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Feasibility Study of Residential Grid-Connected Solar Photovoltaic Systems in the State of Indiana

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A Dissertation

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by

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ABSTRACT

This study aims to measure the financial viability of installing and using a residential grid-connected PV system in the State of Indiana while predicting its performance in eighteen geographical locations within the state over the system's expected lifetime. The null hypothesis of the study is that installing a PV system for a single family residence in the State of Indiana will not pay for itself within 25 years.

Using a systematic approach consisting of six steps, data regarding the use of renewable energy in the State of Indiana was collected from the website of the US Department of Energy to perform feasibility analysis of the installation and use of a standard-sized residential PV system.

The researcher was not able to reject the null hypothesis that installing a PV system for a single family residence in the State of Indiana will not pay for itself within 25 years.

This study found that the standard PV system does not produce a positive project balance and does not pay for itself within 25 years (the life time of the system) assuming the average cost of a system. The government incentive programs are not enough to offset the cost of installing the system against the cost of the electricity that would not be purchased from the utility company.

It can be concluded that the cost of solar PV is higher than the market valuation of the power it produces; thus, solar PV did not compete on the cost basis with the traditional competitive energy sources. Reducing the capital cost will make the standard PV system economically viable in Indiana. The study found that the capital cost for the system should be reduced by 15% - 56%.

PREFACE

This dissertation applied technology management concepts to the field of renewable energy and sustainability to assess the economic benefits of installing a residential PV system in the State of Indiana and analyze the performance of such a system for residential power generation. This study aims to measure the financial viability of installing and using a residential grid-connected PV system in the State of Indiana while predicting its performance in eighteen geographical locations within the state over the system's expected lifetime.

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Last but certainly not the least, I am proud to acknowledge the generous and enduring support and prayers of my mother, my father, my wife, and my sons during this work. I dedicate this dissertation to them.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

CHAPTER 1

THE PROBLEM AND ITS SETTING

Introduction

Different types of renewable energy are increasingly being used throughout the world, including the United States, to meet the growing demand for energy. Tremendous efforts have been invested in the United States to improve residents' awareness of the use of such resources as wind, solar, and biomass energy. In recognition of this fact, the U.S. government, in general, and the state of Indiana, in specific, has offered a number of incentives and programs that help reduce the costs of installing renewable systems to make these systems more affordable for the residents.

Increased use of solar energy via conversion of sunlight into electricity using solar energy systems would likely provide great benefits to nations. Among the solar systems available, photovoltaic (PV) systems would allow households to produce their own electricity with little noise or air pollution. On the larger scale, implementation of PV systems could help diversify energy supply, reduce the amount of imported fuels, improve air quality, offset greenhouse gas emissions, and create jobs related to the manufacturing and installation of solar energy systems. These unique advantages and characteristics make PV systems the ultimate energy sources for the 21st century (Szykitka, 2009). Among the PV solar systems are: PV grid-connected systems and stands-alone PV systems.

This study aims to investigate the use, efficiency, and viability of residential photovoltaic (PV) grid-connected systems in the state of Indiana. The grid-connected systems:

- are comparatively easier and cheaper to install a battery system is not required (Queensland Government, 2002; Elhodeiby, Metwally, & Farahat, 2011; Krigger & Dorsi, 2008);
- have the advantage of effective utilization of generated electricity since there is no storage losses involved (International Energy Agency, 2002);
- enable a reduction in household electric bills (Elhodeiby, Metwally, & Farahat, 2011);
- provide households the opportunity to sell surplus electricity to the local electricity provider (The Indiana Office of Energy Development, 2013) through net metering;
- reduce daytime peak electrical load (The Biosphere Institute, 2011);
- use the grid as a backup system in times of insufficient PV generation (Ali, Pearsall, & Putrus, 2008);
- reduce financial risk and enable household to reduce the volatility in electricity prices;
- produce clean energy with no environmental footprint or greenhouse gas emissions (Komor, 2009);

- save non-renewable fuel resources for future generations by motivating energy efficiency actions ,reducing energy consumption, and self-generating a higher proportion of electricity using these systems (The Biosphere Institute, 2011); and
- stimulate local employment in the solar industry (Komor, 2009).

More advantages for a grid-connected system can be recognized by comparing it to a stand-alone system that:

- produces less energy than a similar sized grid-tied system for two reasons:
  - Storage batteries loss energy during converting the electricity from direct current (DC) to alternating current (AC) (Balfour, Shaw, & Bremer, 2011).
  - Unlike with a grid-tied system, once all of the electrical needs have been met and batteries are full, the excess electricity, which could be produced, has nowhere to go (Pinkham, 2009).
- needs higher initial cost of investment due to the needs of storage batteries and a charge controller. The cost of batteries over time is significant (Balfour, Shaw, & Bremer, 2011).
- requires a greater responsibility from a household to insure safe and reliable operations. On the other hand, the owner of a grid-connected system will have a minimum responsibility and the electric company is the main responsible for insuring a safe and reliable system (Pinkham, 2009).

All these advantages and benefits made the grid-connected system an attractive selection to be investigated (e.g. use, efficiency, and viability) through this research.

The reasons behind selecting the state of Indiana as the focus of this study are:

- Indiana has the highest rate of sulfur dioxide emissions in the United States because of the many coal power plants that are located in the state (EPA, 2013).
- Indiana is in a region of the country that has low average solar radiation of 1642-1825 kWh/m2 annually (Purdue University, 2012; National Renewable Energy Laboratory, 2013). Despite this, in 2009, Indiana was the twentieth top location for solar thermal collectors (EPA, 2013). Therefore, there could be potential benefits gained from using and installing PV systems.
- Indiana has an availability of different incentives programs (e.g., net metering) that are offered and available for solar energy projects (The Indiana Office of Energy Development, 2013) although not all utility companies are a part of this program.

The Importance of Technology Management for Implementing Renewable Energy Systems

As with the installation of any system of energy generation, PV systems installations require a substantial investment, as well as expert assistance and careful planning to assist individuals with different motivations in making more informed decisions. Technology Management (TM) is an important science that helps engineers, managers, and individuals make decisions in their lives. TM has a great influence on individuals, businesses, societies, and nature, and it is necessary to use the fundamentals of this science for making decisions and evaluating the performance of technological systems. TM is an interdisciplinary science that integrates engineering and management practices with a focus on technological innovations as the factor of wealth generation. Therefore, it is important to use TM for making the financial decision regarding investing in the residential PV system in the state of Indiana. At the national or governmental level, technology management has been defined by Khalil (2000) as:

> "A field of knowledge concerned with the setting and implementation of policies to deal with technological development and utilization, and the impact of technology on society, organizations, individuals and nature. It aims to stimulate innovation, create economic growth, and to foster responsible use of technology for the benefit of humankind."

Skinner (1985) affirms that in order to manage technological systems successfully, technology managers have to be familiar with four characteristics of a technology: machine size and needed capacity; general purpose versus special purpose; precision and reliability; and specifications and degrees of mechanization. By identifying these characteristics, technology managers will be able to make more informed decisions about issues such as investment in equipment and materials efficiency.

TM assists the researcher in this study by evaluating the performance and the viability of a standard PV system in the state of Indiana. The researcher uses different technology management strategies and tools to draw the study's conclusions. One important technique was used in this study is the engineering economy analysis (EEA).

EEA is a technique that helps engineers and technology managers make decisions based on quantitative tools through the use of mathematical equations and parameters to analyze and solve problems. The results of the analysis appear in a number and quantity format, which should be interpreted into qualitative decisions that will assist in the management of the use of advanced technologies. Also, this technique will lead to better understanding of complex problems since it measures and expresses the problem in numbers so that technology managers can understand the problem and subsequently control its factors. If technology managers understand the decision-making process and have the necessary tools for obtaining realistic comparisons between alternatives, they will be able to make better decisions (Newnan, Eschenbach, & Lavelle, 2011).

Another advantage of the EEA is that it focuses on analyzing costs, revenues, and benefits that occur at different times, both present and future. The future and its factors are taken into consideration to reduce uncertainty; therefore, making technology managers more confident about making decisions for the future.

Hopp and Spearman (2011) belive that effective technology managers of the future will have to rely on a solid understanding of their systems to enable them to identify leverage points that can be used to engender an environment of continual improvement. Mathematical equations form a qualitative and quantitative understanding for important parameters (and their relationships) that affects the decision of investing in advanced technologies such as PV systems. Therefore, based on the qualitative and quantitative understanding, technology managers will be able to make certain decisions without being afraid of the future challenges. Kelvin (1883) asserts that

> “I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but have scarcely, in your thoughts, advanced to the stage of Science, whatever the matter may be.” (Kelvin, 1883; Kiser, 2010)

As a result of using TM, the results of the study could benefit not only the residents of Indiana but also the decision makers, who might be able to identify situations for using PV systems in the state as well as make decisions that help in meeting future challenges and creating economic growth.

Statement of the Problem

While the use of green energy has gained popular support and efforts have been made to market it, few studies have investigated the economic advantages and the savings that could be gained by implementing green solutions (including PV systems) for energy challenges. In order for PV systems to become a practical solution for Indiana residents, they must be perceived as attractive financial investments for their owners. The lack of knowledge regarding the economic assessment of installing and using a residential grid-connected PV system has resulted in a low number of homeowners installing the systems in the state.

In order to address this knowledge gap, this study aims to measure the financial viability of installing and using a residential grid-connected PV system in the State of Indiana while predicting its performance in different geographical locations within the state over the system's expected lifetime.

To evaluate the financial feasibility of installing and using a standard residential grid-connected PV system in the State of Indiana, data regarding the locations of the counties in Indiana have been collected, evaluated, and analyzed using quantitative and systematic methods. Data regarding the costs and size of a standard system were collected from professionals working in the PV industry through online quotes.

Statement of the Hypotheses and Research Questions

The null hypothesis of the study is that installing a PV system for a single family residence in the State of Indiana will not pay for itself within 25 years. This means that government incentive programs are not enough to offset the cost of installing the system against the cost of the electricity that would not be purchased from the utility company. The alternative hypothesis is that installing a PV system in a single family residence in the State of Indiana will pay for itself within 25 years assuming the average cost of a system. This means that government incentive programs are enough to offset the cost of installing the system against the cost of the electricity that would not be purchased from the utility company.

The results of the analysis are used to answer the following research questions:

1. What is the precise size of a PV system suitable for a typical single family home in Indiana?
2. How much does a standard PV system cost?
3. How much electricity will a standard PV system produce?
4. By how much will a standard PV system reduce electricity expenses?
5. Is the standard PV system, without government subsidy support, financially attractive investments to Indiana homeowners?
6. Does the Federal tax credit make it a good investment?
7. What is the payback period for a standard PV system?
8. What is the internal rate of return for a standard PV system?
9. How will future electric rate increases impact financial metrics, specifically internal rate of return?

Statement of the Assumptions

This study is based on the following eleven assumptions: 1) the PV system is assumed to be integrated within the utility grid, eliminating the need for investing in batteries or an electrical storage system; 2) the data obtained using the PV Watt application, a performance calculator for on-grid PV systems, is assumed to be an accurate predictor; 3) the analysis period for this study is 25 years because the warranty that is provided by the PV professionals in Indiana is 25 years, so it assumed that is a reasonable lifetime; 4) the market interest rate will remain steady at 3% (Indiana Department of Revenue, 2012); 5) it is assumed that the net metering program is available in all the areas and for all the residents of Indiana; 6) it is assumed that PV energy production degradation is equal to 3% per year (Energy Efficiency & Renewable Energy, 2008; El–Bassiouny & Mohamed, 2012; Jha, 2010); 7) it is assumed that the end of life decommissioning cost is equal to end of life salvage price; 8) it is assumed that the average electricity cost will increase in a constant pattern over the lifetime of the system at an annual rate of 1.052 % without considering the impact of the new U.S, Environmental Protection Agency (EPA) regulations (U.S. Energy Information Administration, 2012; Edison Electric Institute, 2006; Indiana Utility Regulatory Commission, 2012; Americas Power, 2012); 9) it is assumed that the selected counties, which are the counties with the highest population in each geographical area, are typical of that area of the state of Indiana; 10) it is assumed that tilt is equal to latitude and azimuth is equal to true south to avoid shading; 11) and it is also assumed that a typical single family in the state of Indiana consumes 11000 kWh / year and it has 25 appliances, which are described in more details in the literature review chapter (U.S. Department of Energy, 2012; Energy Efficiency and Renewable Energy Clearinghouse, 2012; Electric Consumer , 2011; U.S. Energy Information Administration, 2012).

Statement of the Limitations

Following are the four limitations of this study: 1) The study has not attempted to track time sensitive changes that may have occurred over time that may skew the findings; 2) the amount of the electrical energy produced by a standard system is based on the location and on the average daily solar radiation expected of each location; 3) electricity rate variations from one location to another are not in the control of the researcher; and 4) the increase in electricity rate fluctuates from one year to another cannot be accurately predicted (Islegen & Reichelstein, 2009).

Statement of the Delimitations

There are six delimitations of this study: 1) the body of knowledge regarding PV systems presented in this study is based on a review of the literature available to the researcher at the time of the study; 2) data about the system cost relies on information collected from online quotes; 3) data regarding electricity generation and the system's performance was obtained from the U.S. Department of Energy website using the PV Watt application; 4) this study is specifically limited to investigate the viability of a residential grid-connected PV system in the state of Indiana; 5) the study considers the real electricity prices in 2013 U.S. dollars (nominal dollars); and 6) the advantages of a feed-in tariff program were not considered in this study since few utility providers adopt this program.

Statement of the Purpose and Need

This study is intended to provide useful information to Indiana residents and homeowners considering the installation of a standard PV system as a means of reducing the cost of electricity. While many Indiana residents may be driven, in part, by ecological or patriotic motivations, financial reward may also be a consideration. This study provides an understanding of the economic feasibility of installing and using a residential PV system in the State of Indiana while predicting the system's performance over its lifetime.

This study contributes to developing energy policies in the state of Indiana, by providing an independent analysis of the economic feasibility of using the grid-connected PV systems. Though many financial incentive programs have been initiated by the state, only a few have been applied (Andrews, Elisabeth , 2008). The results of the study may help Indiana decision makers to evaluate the real needs and the applicable situations for using the residential PV system. This study provides the decision makers with information about assessing sites within Indiana Counties (and cities) for the installation of PV systems and measuring the impact of the selected sites on system performance. In addition, the study provides information that may assist in the development of strategies and financial incentives that could make the PV system financially attractive and encourage Indiana residents to install such systems in their homes.

This study considered:

- a standard PV system that satisfies a typical family need in the state of Indiana;
- a PV grid-connected system for residential purposes; and
- future electricity price increases.

The specific objectives of the study were:

1. To determine the suitable and standard size of a residential PV system for average Indiana households.

2. To estimate the energy generation of a standard PV system and determine areas with high solar potential.
3. To gain understanding of the economic benefits of using a standard PV system.
4. To identify the factors that should be considered when determining the economic payoff of installing and using a PV system in terms of electricity rate, system performance, and incentives.
5. To use US Department of Energy recommendations and methodologies to develop a model for building a standard PV system.
6. To evaluate the current policies toward installing a standard residential PV system in the state of Indiana.
7. To determine the areas suitable for installing a commercial PV system in the State of Indiana.

Statement of the Methodology

Data regarding the use of renewable energy in the State of Indiana was collected, using a systematic approach consisting of six steps, from the website of the US Department of Energy to perform feasibility analysis of the installation and use of a standard-sized residential PV system. The data was evaluated by conducting different engineering economic analyses and then charts were created to summarize the findings.

Definitions of the Key Terms

Cash flow: Cash flow is an important concept in engineering economics science defined as the process of tracking the movement of money in or out of a business project (Newnan, Eschenbach, & Lavelle, 2011).

Discounted payback period (DPP): The number of periods until the compounded sum of net revenues equals the compounded value of the initial cost (Newnan, Eschenbach, & Lavelle, 2011).

Internal rate of return: The internal rate of return (IRR) is the rate used in capital budgeting to measure the viability and profitability of a project to help decision makers make the correct decision regarding a specific business project (Newnan, Eschenbach, & Lavelle, 2011).

Market interest rate: Market interest rate is the rate of interest offered on cash deposits. The rate is determined by financial institutions. Determining the rate requires studying the demand and supply of deposits, the duration, and amount of deposits (Newnan, Eschenbach, & Lavelle, 2011).

Minimum attractive rate of return (MARR): The minimum required interest rate for invested money (Newnan, Eschenbach, & Lavelle, 2011).

Payback period: The payback period is the period required to pay back the money that has been invested as share capital to start a business project. Its determination assists managers and decision makers in making the correct decisions when investing in a business project (Newnan, Eschenbach, & Lavelle, 2011).

Project Balance: The project balance is the amount of money available over the life time of a project. It represents the loss or profit associated with the cash flow at any moment of the project life.

PV array: A PV array is part of PV solar system that consists of sets of PV panels or modules that are connected together in a series or in parallel (Pagliaro, Ciriminna, & Palmisano, 2008).

PV cell: A PV cell is a solar cell that absorbs sunlight that consists of at least two layers of semiconductor material, one with a negative charge and one with a positive charge (Peumans, Yakimov, & Forrest, 2003). It is the most important component of a PV system.

PV panel: A PV panel is a solar panel consisting of sets of PV cells that are connected together. It is also known as PV solar module (Pagliaro, Ciriminna, & Palmisano, 2008).

PV system: A PV system is a solar system designed to absorb sunlight and convert it into electricity. It consists of sets of PV arrays or modules connected to other equipment, such as electric inverters or raking systems, and functions as a single electricity-producing unit (Sen, 2008).

Renewable energy: Renewable energy is the energy that is generated using natural resources, such as solar, wind, rain, hydro, and geothermal sources (McKinney, Schoch, & Yonavjak, 2007).

Solar altitude: The U.S Department of Energy defines the solar altitude as "the angle between the horizon and the center of the solar disc" (2009). The American Meteorological

Society defines it as “the angle of the sun 90 degrees or less above the horizon” (AMS journals, 2012).

Solar azimuth: The US Department of Energy defines the solar azimuth as “the angle between the sun's apparent position in the sky and true South, as measured on a horizontal plane” (2009).

State of Indiana: The State of Indiana is a US state located in the Midwest region with a population of 6,516,922 (Sisson, Zacher, & Cayton, 2006). According to the Rural Policy Research Institute, 77.7% of Indiana residents live in metropolitan counties, 16.5% in micropolitan counties, and 5.9% in non-core counties (Rural Policy Research Institute, 2006).

Technology: The International Network for Small and Medium Sized Enterprises (INSME) defines technology as “a human innovation in action that involves the generation of knowledge and processes to develop systems that solve problems and extend human capabilities” (INSME Association, 2012). In other words, technology is any process that can improve human knowledge by solving problems and making life easier.

Management: Management is the act of organizing people to achieve certain goals. According to Henri Fayol (1917), who developed the theory of the Management Science, the most important activities of management are forecasting, planning, organizing, commanding, coordinating, and controlling (Fayol, 1917).

Technology management: Technology management is the science that focuses on investing in technological tools to manage, assist, and motivate innovation. Khalil (2000) defines technology management as “a field of knowledge concerned with the setting and implementation of policies to deal with technological development and utilization, and the impact of technology on society, organizations, individuals, and nature"(p. 12). This science aims at stimulating innovation and creating economic growth for nations by fostering responsible use of technology for the benefit of humanity (Khalil, 2000; Schilling, 2009).

Summary

This chapter provided a basis of relevant research from which to identify a needed extension of research into the viability of PV systems. This was further developed with the examination of data that was collected from the website of the US Department of Energy. A background was provided for an assessment methodology for conducing economic feasibility analyses of installing and using a residential standard-sized PV system in the State of Indiana while considering the system's performance over its lifetime.

CHAPTER TWO

REVIEW OF THE RELATED LITERATURE

Overview

Energy is the essence of nations' technological and economic growth. Countries all over the world face different energy challenges such as the environmental challenges caused by global warming. The energy choices made by a nation have impacts on the local, national, and global environment. This chapter discusses both the availability of energy resources and their global use. Moreover, this chapter focuses on exploring the importance of using such renewable energy resources as solar energy, in the United States and in the State of Indiana specifically. To this end, solar energy and photovoltaic systems are discussed in great details through case studies investigating the viability of photovoltaic systems to provide the reader with a theoretical basis for and a greater understanding of the nature of the research.

Energy Process

The process of using energy goes through three phases: identifying an energy source, producing and transferring energy, and consuming energy. The energy source explains where energy comes from (e.g. coal, sun, or wind). Energy transfer and production describes the process of transferring energy from one form to another through technologies. This phase is also called producing energy. Lastly, energy consumption describes how the energy will be used efficiently.

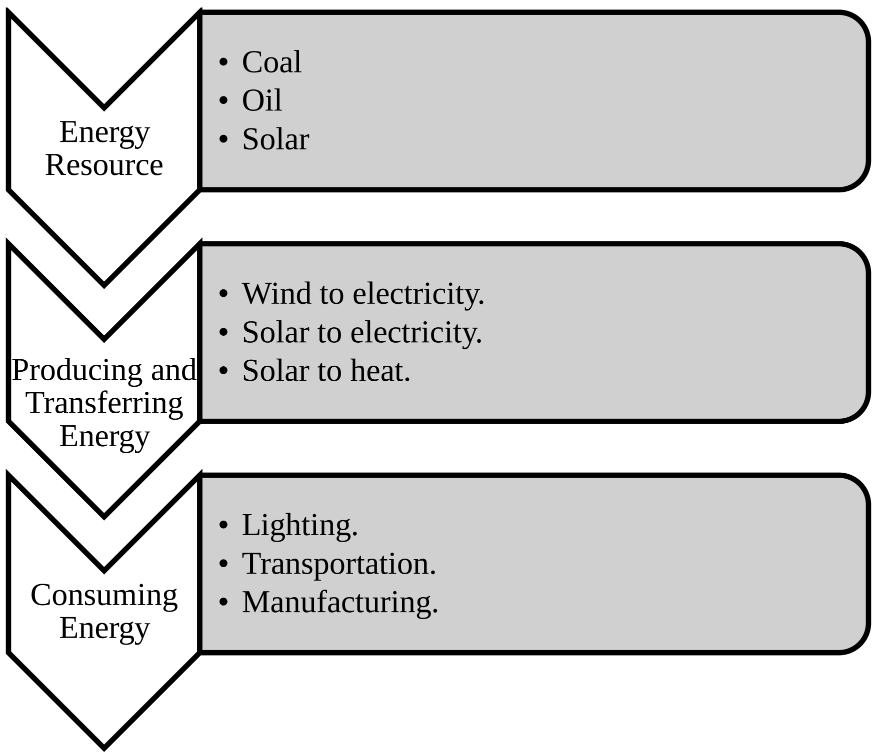

Figure 1: Energy Process

Energy Resources

Energy resources can be classified into three main categories: fossil fuels, mineral resources, and renewable energy.

Fossil fuels

Fossil fuels are “fuels formed by natural processes such as anaerobic decomposition of buried dead organisms. The age of the organisms and their resulting fossil fuels is typically millions of years, and sometimes exceeds 650 million years” (Hall, 2013). Fossil fuels form from the fossilized remains of dead plants and animals by exposure to heat and pressure in the Earth's crust over millions of years (Demirbas, 2009).

Three main types of fossil fuels are used for producing energy: petroleum, coal, and natural gas. Although estimates vary, economically recoverable fossil fuel reserves include more than 1 trillion barrels of petroleum, about 1 trillion metric tons of coal, and over 150 trillion cubic meters of natural gas (Kennedy, 2006). According to the Energy Information Administration (2007), 86.4% of the total energy consumption in the world is estimated to be covered by fossil fuels — 36.0% using petroleum, 27.4% using coal, and 23.0% using natural gas.

Mineral resources

A mineral resource is a volume of rock enriched in one or more useful materials. Mineral resources are divided into two major types—metallic and non-metallic. Metallic resources include gold, silver, tin, copper, lead, zinc, iron, nickel, chromium, and aluminum. Non-metallic resources include materials such as sand, gravel, gypsum, halite, uranium, and dimension stone. Among these, over three million metric tons of uranium reserves represent important mineral resources for energy generation (Nelson, 2012).

Renewable energy

Renewable energy is energy obtained from resources that are continually and sustainably replenished and available throughout the world. According to the Natural Resources Defense Council (2012), there are five main sources of renewable energy: wind, solar, biomass, biogas, and geothermal. Of these, solar energy and photovoltaic technology, as the focus of this study, is covered in greater detail in the next sections.

Over the past 60 years, the increase in global population has resulted in an increased demand for energy at a rate that is larger than production rate thus resulting in an oil price crisis. This high demand for energy forces countries to import more quantities of fossil energy. Figure 2 shows the increase in the daily production for the fossil energy.

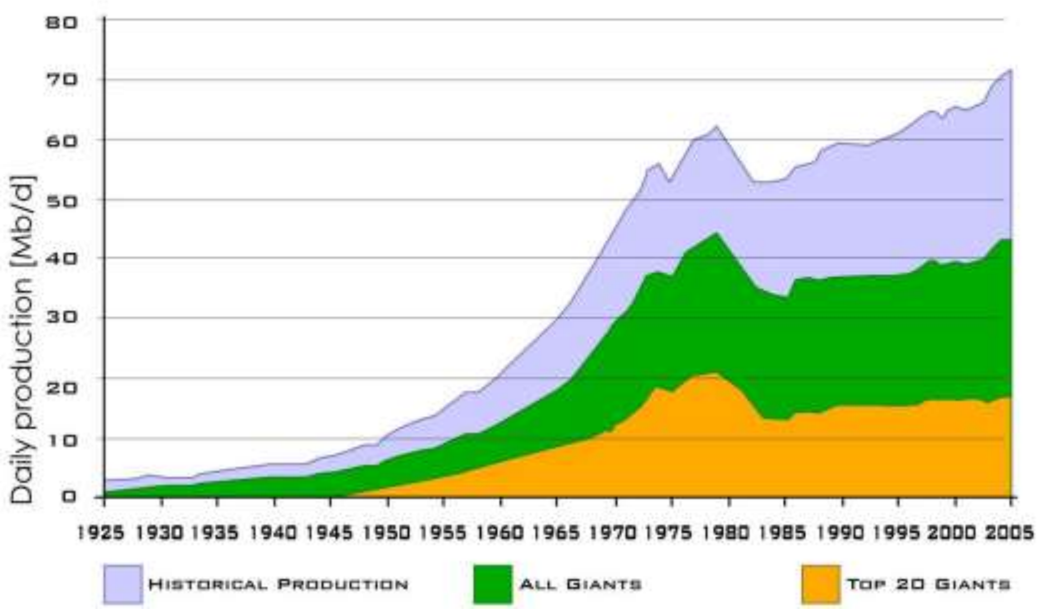

Figure 2: Fossil Energy Production per Day (Stanford University, 2005)

The more fossil energy produced, the more problems (e.g., environmental issues) will be created. Using fossil resources presents additional environmental and social costs, which limit the future viability of these resources. Moreover, concerns regarding waste disposal and fears over weapons proliferation have limited both the growth and the development of mineral resources and nuclear power. Hence, the limitations facing fossil fuels and nuclear power have driven many world governments to find alternative energy resources in order to meet the high demand of energy, to solve the global warming problem, and to reduce imported energy.

Renewable energy production provides many benefits and advantages, foremost among which are the following:

1. Renewable energy production is environmentally friendly: Renewable power is a clean source of energy that has less impact on the environment compared to other energy resources (Abbasi & Abbasi, 1999).
2. Renewable energy production is sustainable: Unlike other finite sources of energy, renewable power is continually and sustainably replenished, and will thus not run out (Abbott, 2010).
3. Renewable energy production provides energy security: Renewable energy production reduces the need to import oil from other nations, increasing self-reliance in domestic energy production (Schmitz, 2011).
4. Renewable energy production creates infrastructure and jobs: Renewable energy production requires domestic investment in technology and employment of domestic workers, leading to investment in domestic infrastructure and human resources rather than overseas resources and employment (Tickell, 2006).

Renewable Energy in the United States

Biomass energy, energy generated by burning plant materials, such as wood, corn, and soy, as well as hydroelectric energy, electricity generated using the gravitational force of falling or flowing water, were the dominant sources of renewable energy consumed in the U.S until the early 2000s. Subsequently, during the last 10 years, the use of corn-based ethanol and wind energy has increased as a result of government support and regulations (Purdue University, 2012). The U.S. government, for instance, initiated the Federal Renewable Fuel Standard on 2000, the Energy Policy Act on 2005, the Federal Production Tax on 1992, and renewable portfolio standards (IN.GOV, 2012).

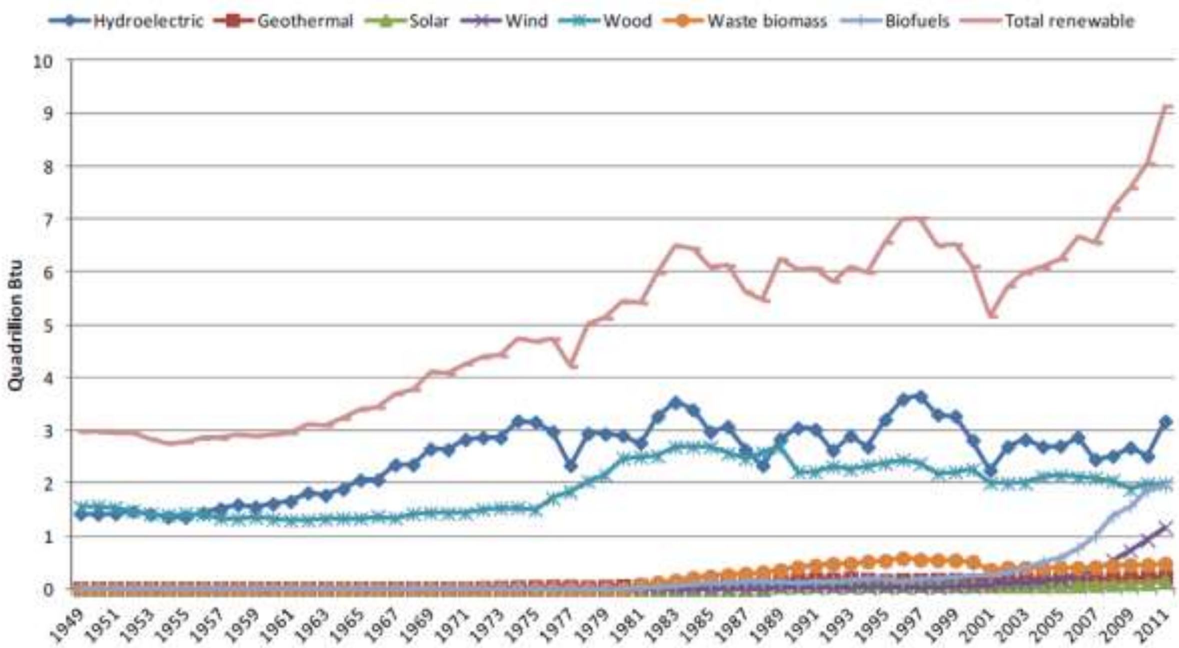

Figure 3: Renewable Energy Consumption in the United States (1949-2011) (Energy Information Administration, 2011)

However, renewable energy resources still provide less than 10 percent of the total energy consumed in the U.S., leaving more than 80 percent provided by fossil fuels, while the rest is supplied by nuclear energy. The sources of total energy consumed in the U.S. from 1949- 2011 are illustrated in the Figure 4 (Energy Information Administration, 2011).

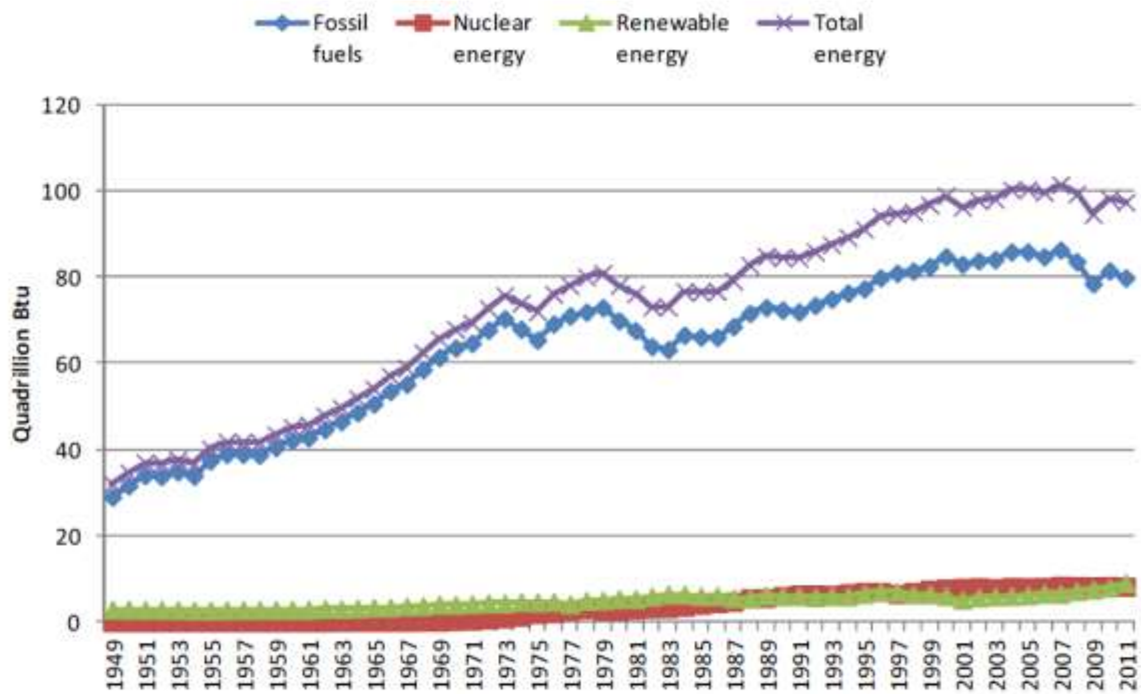

Figure 4: Total Energy Consumed in the United States (1949-2011)

In 2011, petroleum resources remain the main energy source, supplying 36 percent of the total energy consumed in the U.S., followed by natural gas supplies at 26 percent, and 20 percent comes from using coal. In contrast, regarding the use of renewable resources, biomass energy supplies about 50 percent of the total renewable energy, hydroelectric energy provides 35 percent, wind energy contributes 13 percent, only 2 percent is provided by geothermal energy, and 2 percent also comes from using solar energy (Energy Information Administration, 2011).

In the context of electricity generation using renewable resources, hydroelectricity energy is the dominant resources, contributing 60 percent of total electricity generation in the U.S., while wind energy contributes 22 percent, wood biomass takes third place at 9 percent, waste biomass and geothermal provides 4 percent, and 0.3 percent comes from using solar energy (Purdue University, 2012).

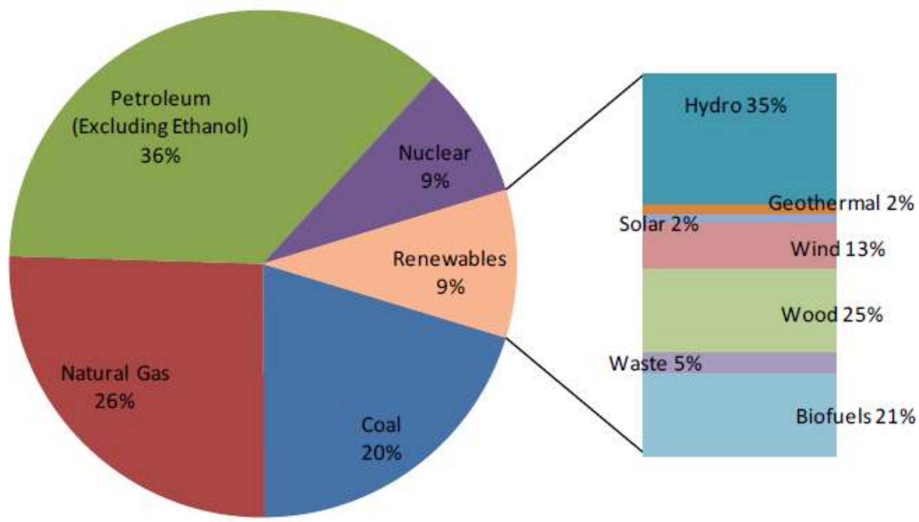

Figure 5: Total Consumptions of energy in the United States in 2011 (EIA, 2012)

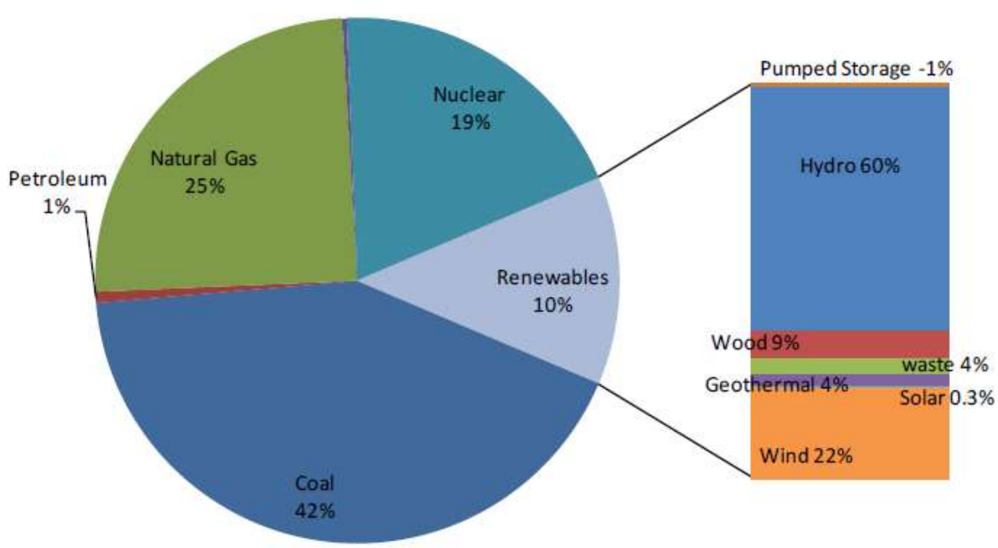

Figure 6: Total Electricity Generation in the United State in 2011 (EIA, 2012).

Renewable energy in Indiana

The State of Indiana is located in the Midwest region of the United States and characterized by a humid climate, with cold winters and warm summers. The total area of the state is 36,418 square miles (Sisson, Zacher, & Cayton, 2006; Rural Policy Research Institute, 2006)), makes it the 38th largest state in the United States (National Atlas of the United States, 2012). Indiana is divided into 92 counties, and as of 2011 contained 16 metropolitan areas, 25 micropolitan areas, 117 incorporated cities, and 450 towns. Indianapolis is the largest city and the capital (United States Census Bureau, 2011). The cities with populations larger than 55,000 are Indianapolis, Fort Wayne, Evansville, South Bend, Carmel, Bloomington, Hammond, Gary, Fishers, Muncie, Lafayette, Terre Haute, and Anderson. As of July 1, 2011, the population of Indiana was 6,516,922 inhabitants (United States Census Bureau, 2011). The state has a maximum east-to-west dimension of 145 miles and a maximum north-to-south dimension of 250 miles. The State of Michigan is located on the northern border of the state, while the State of Ohio located on the eastern border, and the State of Illinois on the western border of the State (National Atlas of the United States, 2012).

The main source of power production in the State of Indiana is coal. There are 24 coal power plants in the state, including the Gibson Generating Station, the largest coal power plant in the United States (U.S. Department of Energy, 2012). Not surprisingly, the state has the highest rate of sulfur dioxide emissions in the United States because of the many coal power plants that are located in the state (Citizens Action Coalition Education Fund, 2007). Figure 7 shows the sources of electricity in the state of Indiana, 93.1% of electricity is generated using the coal and only 1.2% using wind energy.

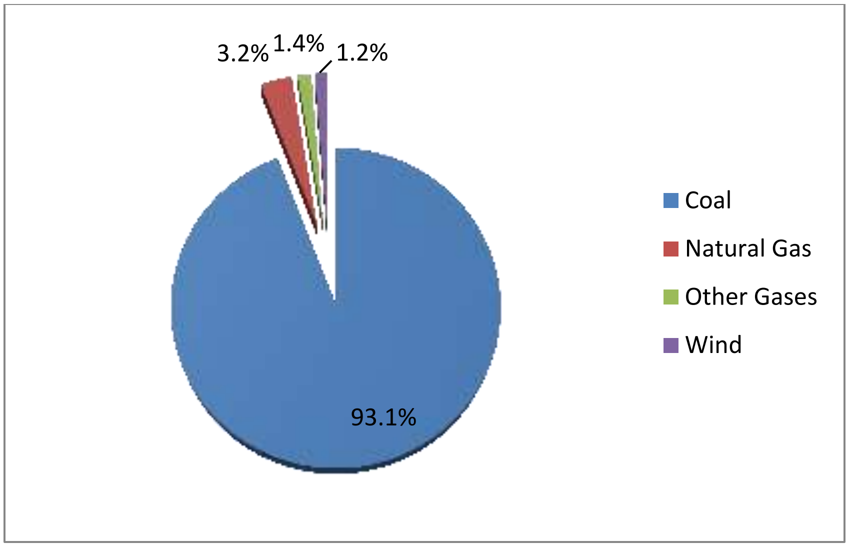

Figure 7: Electricity Generation in the State of Indiana (Institute for Energy Research, 2011)

According to the U.S. Department of Energy (2010), in Indiana's rate of renewable energy consumption is 4.9 percent. Ethanol and wind resources have been among the most effective resources since 2006. Before 2006, woody biomass was the main source of renewable energy, contributing more than 80 percent of the total renewable energy in Indiana.

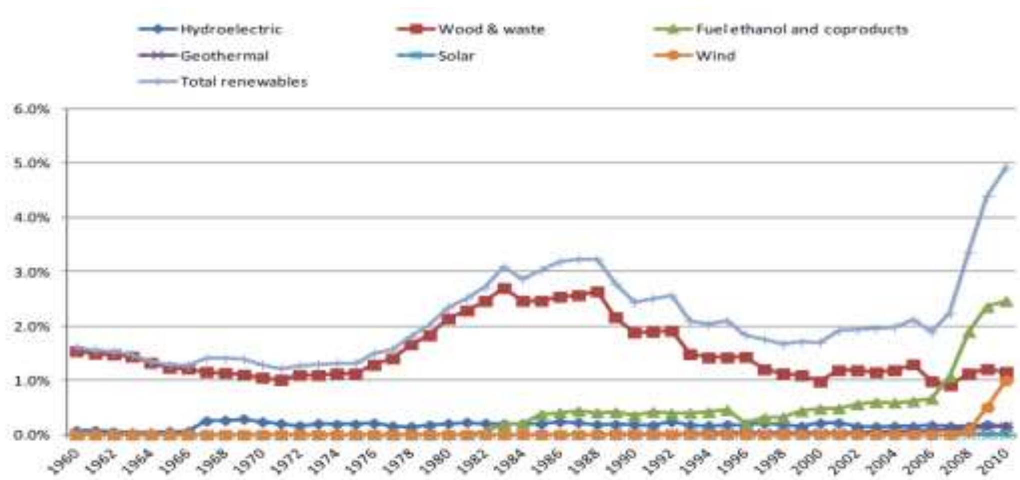

Figure 8: Indiana Total Energy Consumption from Renewable Resources (U.S. Department of Energy, 2012)

Hydroelectricity was the main renewable source of producing electricity in Indiana until 2007. In 2010, wind energy became the dominant form, supplying 2.4 percent of energy generation, while hydroelectricity contributes 0.4 percent to electricity generation (U.S. Department of Energy, 2012).

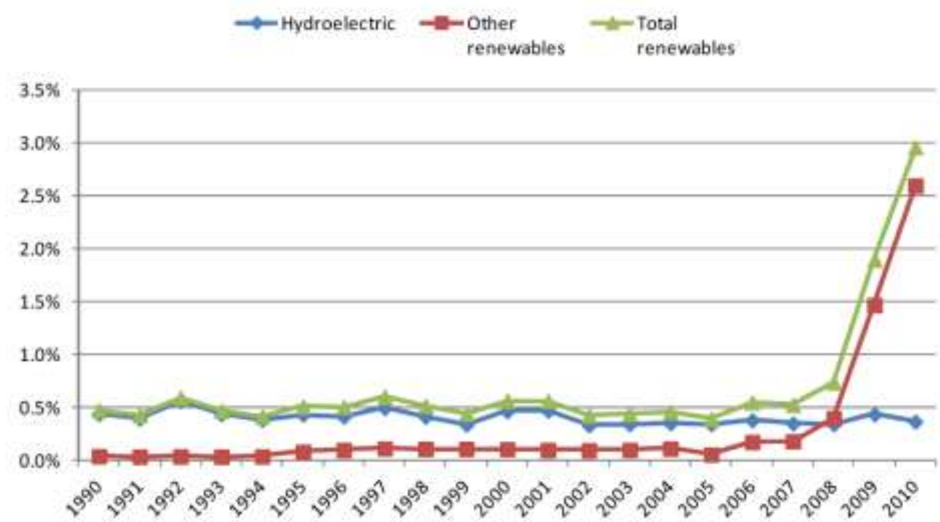

Figure 9: Indiana Total Electricity Generation Using Renewable Energy (U.S. Department of Energy, 2012)

Progress in Renewable Energy Development in Indiana

Despite many efforts to enlarge the green energy sector in Indiana, progress has been very slow, primarily due to the large coal deposits in southern Indiana. One illustration of such lack of progress is the State of Indiana's inability to establish a renewable portfolio standard (RPS), a goal regarding the percentage of energy that is generated from renewable resources. Among states that have established an RPS, Illinois aims to generate 25% of the state's power using renewable resources by 2015 and Michigan 10% by 2015 (Andrews, Elisabeth , 2008). Figure 10 shows the RPS for each state in the U.S..

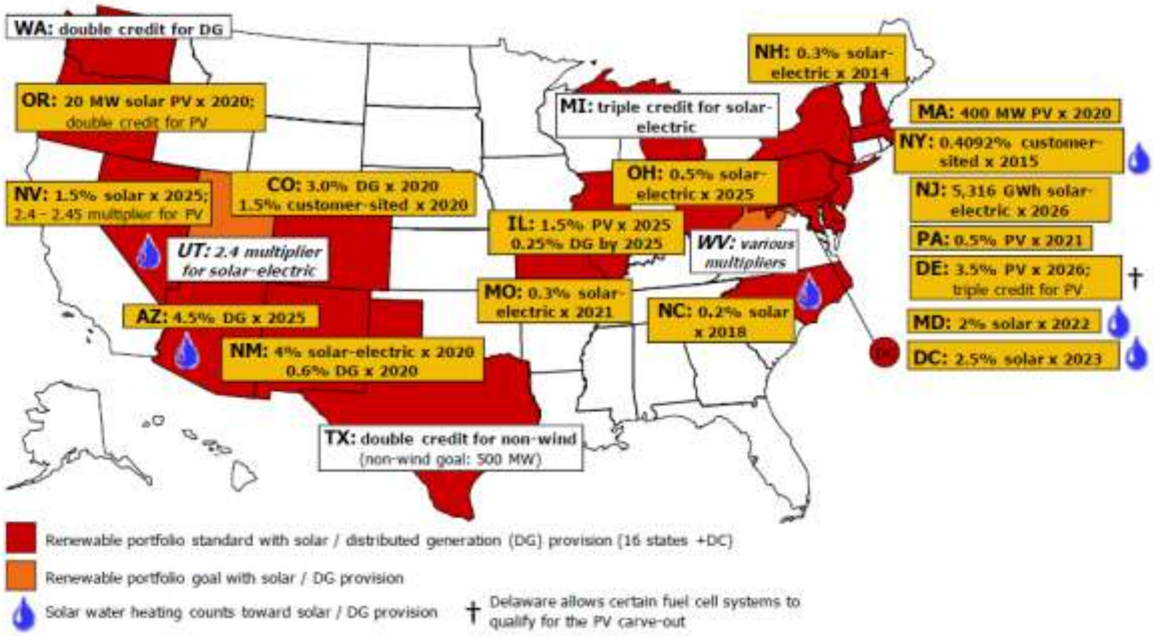

Figure 10: Renewable Portfolio Standards in the United States (Database of State Incentives for Renewables and Efficiency, 2013)

Solar Energy

The sun has been the earth's source of heat energy since before the beginning of life. According to Smil (1991), the earth receives about 174 pet watts (PW) of sun radiation, and about 70 percent of incoming solar radiation is absorbed by the earth's land surface, oceans and atmosphere. This huge amount of energy should be used and invested in more useful applications. The process of transferring the power of the sun to another form of energy such as electricity and making it a more efficient and practical source is called solar energy.

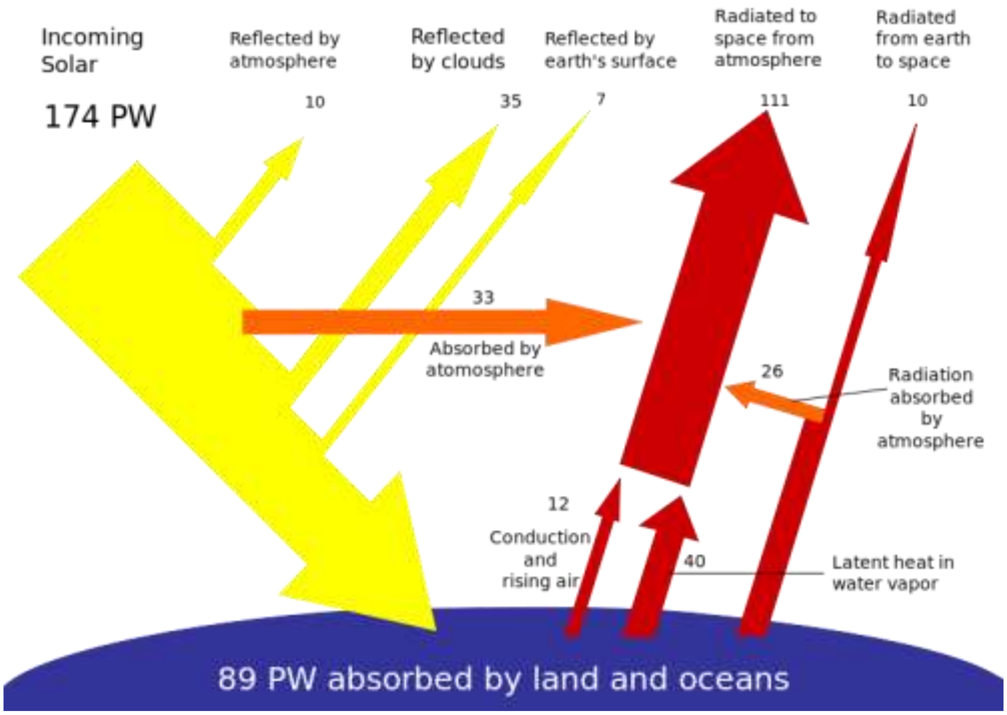

Figure 11: The Incoming Solar Radiations Reaches the Earth (Smil, 1991).

In the U.S., significant solar resources are available, especially in the southwestern region. Every square yard of land receives about 833 watts of solar energy. Sunlight provides useful solar energy for about 6 hours per day, so, 4,998 watt-hours (6*833) of solar energy could be generated per day (Energy Independence, 2013). Figure 12 shows the U.S. potential of solar radiations.

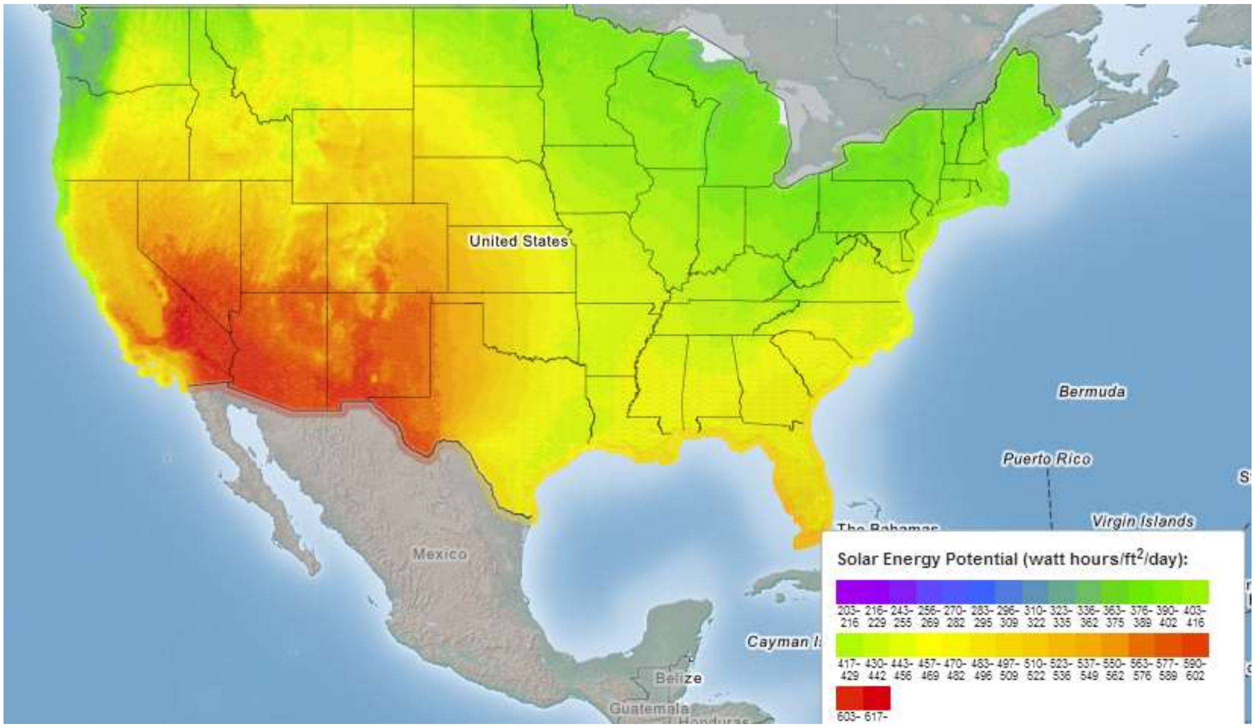

Figure 12: Solar Energy Potential in the United States (U.S. Department of Energy, 2013)

Solar Energy in Indiana

Indiana's geographical location means that it has a low annual average solar radiation of 4-5 kWh/m2/day (National Renewable Energy Laboratory, 2007). Therefore, it would not be the best location for generating a huge amount of electricity. However, there is a potential investment for this amount of solar radiation in small-to-medium electricity generation projects (e.g., residential) or water-heating applications. Evidence for this potential can be seen in that, in 2009, Indiana was the 20th top location for solar thermal applications (Energy Independence, 2013). Figure 13 shows the solar radiation available to a PV system facing south in Indiana. The southern half of the state has more radiation available.

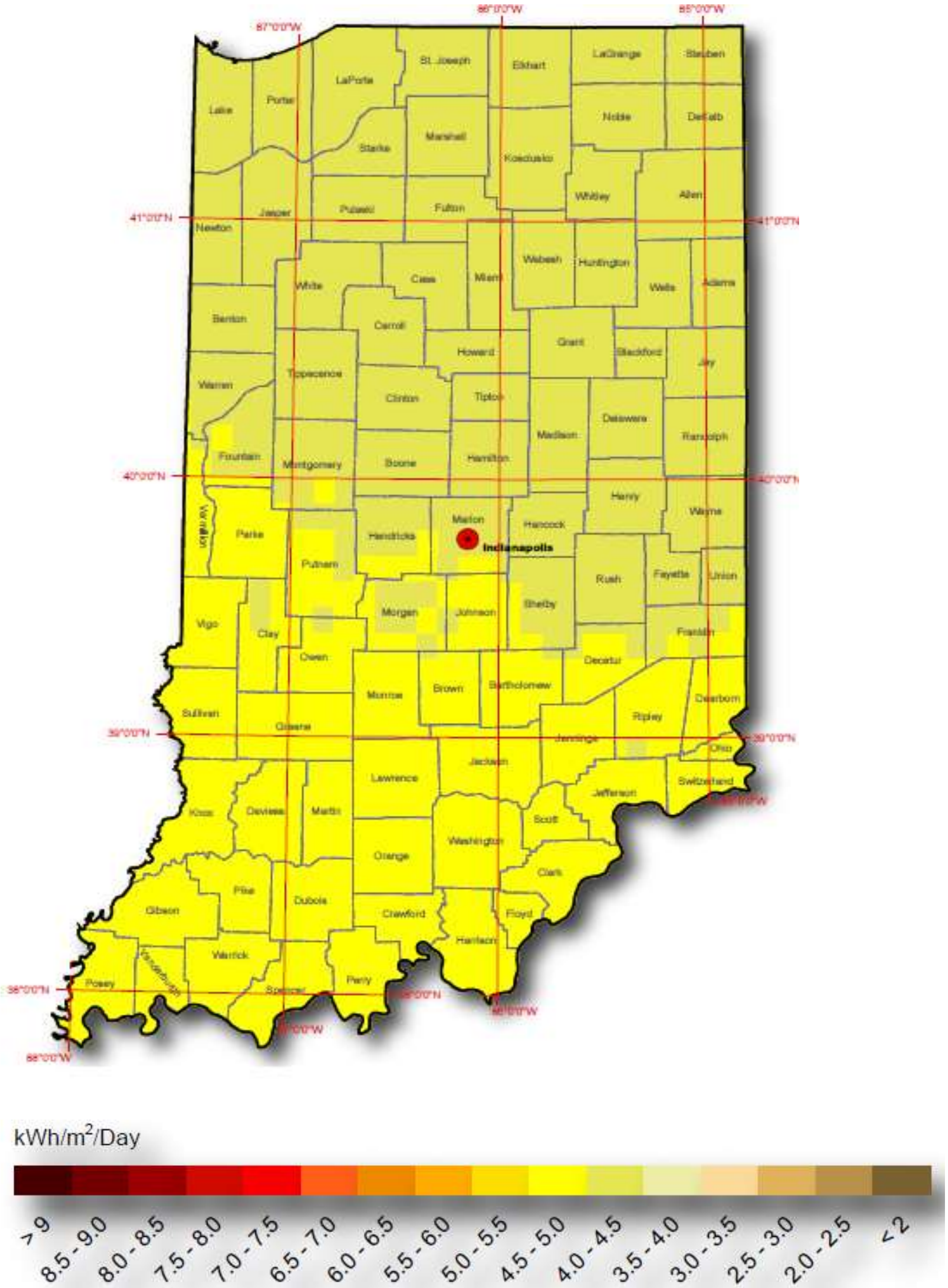

Figure 13: The Solar Radiation Available to a PV System Facing South in Indiana (National Renewable Energy Laboratory, 2007)

Solar Energy Systems and Applications

Solar energy is a clean and free source of energy, and many features makes it more economical for use in human life. Solar energy is environmentally friendly and using it helps reduce pollution. There are mainly two useful applications for solar energy: photovoltaic solar panels (direct conversion) or solar thermal conversion technologies (indirect conversion) (Lawal, 2010). This study focuses on the use of photovoltaic solar panels.

Solar thermal technologies can be used for electricity or water and space heating. Electricity-generation projects use a special type of solar thermal technology called concentrating collectors, which use multiple mirrors with various configurations to direct the solar energy onto a receiver containing a fluid that transfers the heat to a conversion engine (Sorensen, 2010). Figure 14 shows the dish/engine system, which is one type of concentrating collectors.

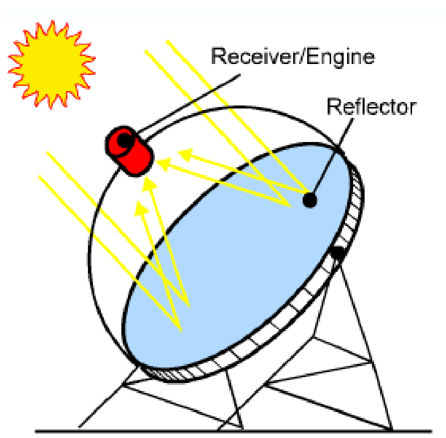

Figure 14: One Type of Solar Concentrating Collectors (Sorensen, 2010)

Water and space heating systems use non-concentrating collectors, which consist of an absorber, a cover that allows solar energy to pass through, a heat-transport fluid flowing through tubes, and a heat insulating backing. Figure 15 shows a cross-sectional view of flat-plate designs, which is the most common type of non-concentrating collectors.

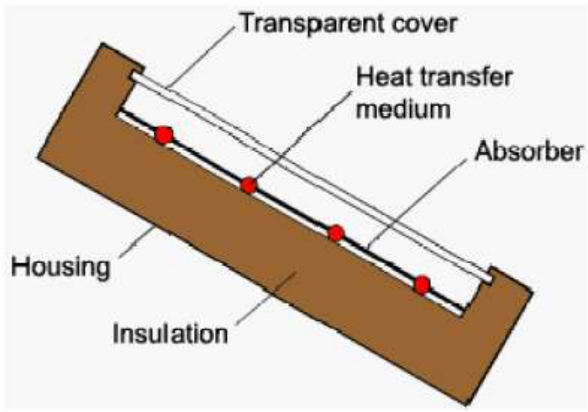

Figure 15: The Most Common Type of Non-Concentrating Collectors (Sorensen, 2010)

Photovoltaic (PV) systems

The word photovoltaic consists of the term photo, a Greek term referring to light, and voltaic, a Latin-derived term referring to the production of electricity (Sunil, Raja, & Vasantha, 2008). PV systems are referred to as solar cell systems because they use solar panels to absorb solar energy and convert it into electricity. PV systems are also used to produce electricity in a clean, quiet, and reliable way, Figure 16 depicts an example of one type of PV system.

Figure 16: Example of One Type of PV System (Go Green Heat Solutions, 2012)

PV system Components

All PV systems consist of the two primary components—a set of PV panels (modules) and an AC/DC power converter or inverter—and may contain additional components, such as a battery, solar tracker, interconnection wiring system, and/or racking system that holds the solar panels. Regarding the primary components, PV panels consist of PV cells that contain at least two layers of semiconductor material, one with a negative charge and one with a positive charge, connected into groups referred to as solar arrays. An inverter is an electrical power converter used to change the direct current (DC) at the source to alternating current (AC) at the destination (Maghraby, Shwehd, & Al-Bassam, 2002). Figure 17 depicts PV cells, panels, and arrays and Figure 18 summarizes the most important components of a PV system.

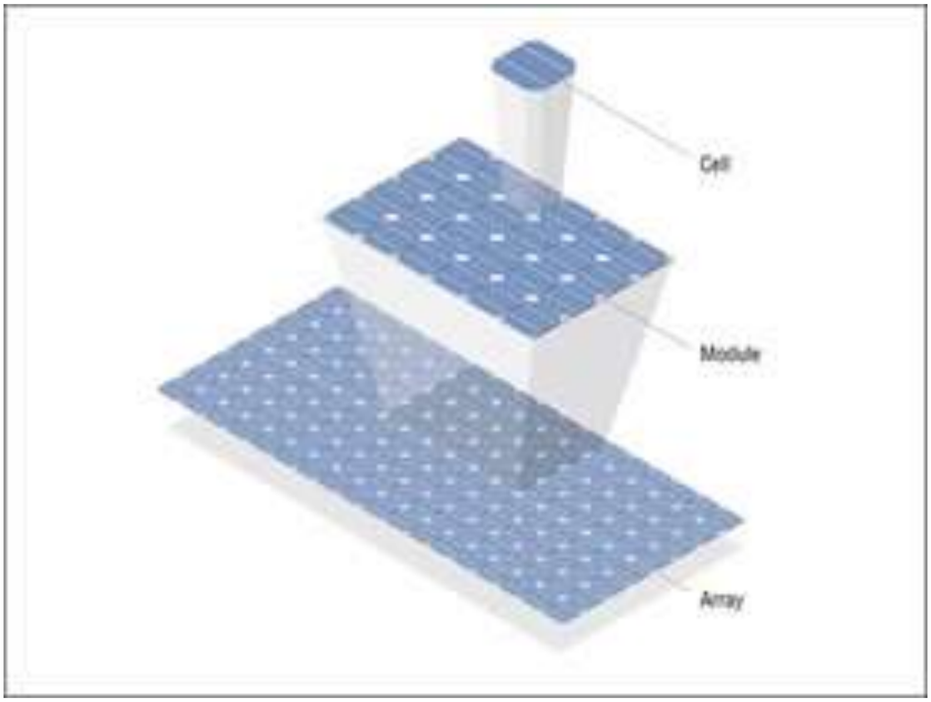

Figure 17: PV Cell, Panel, and Array (Grebski, 2012).

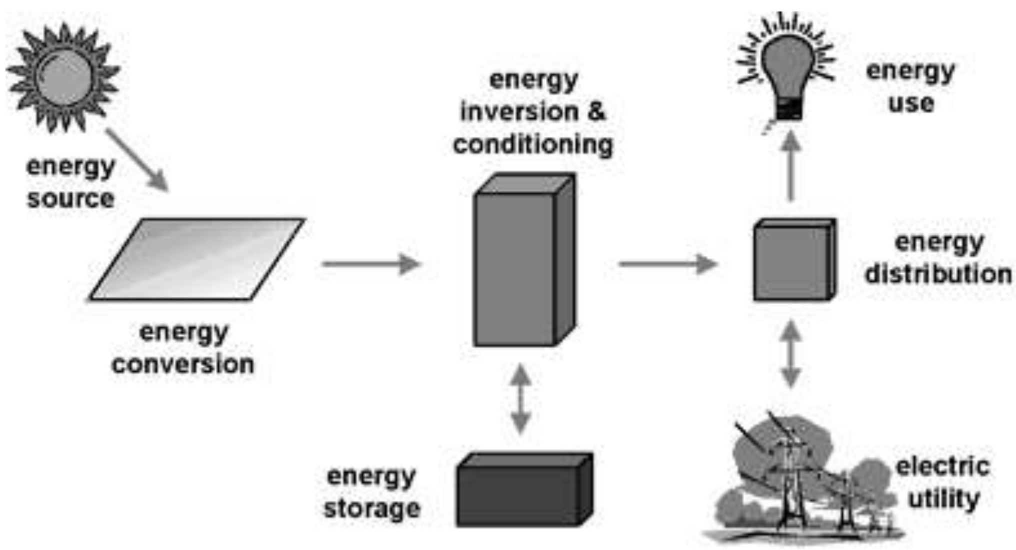

Figure 18: Major PV Components (Florida Solar Energy Center, 2007).

PV System Functioning

According to Balfour, Shaw and Bremer (2011), the manner in which a PV system works can be summarized in the following four steps:

1. When sunlight strikes a PV cell, the photons of the sunlight are absorbed by the atoms of the semiconductor material.
2. Electrons become negatively charged, activating chemical reactions that release the electrons.
3. As the free electrons move from the cell's negative layer to an external circuit and back to the positive layer, a direct current of electricity is produced.
4. The inverter converts the DC electricity produced by the PV cells to AC energy, the form in which it is used by households.

Increasing the number of PV cells and panels that are connected to the PV system allows for the production of more electricity. Connecting two panels in a series doubles the voltage and it stays constant, when two panels are connected in parallel (State Energy Conservation Office, 2012). Figure 19 depicts the process of producing electricity from a PV system.

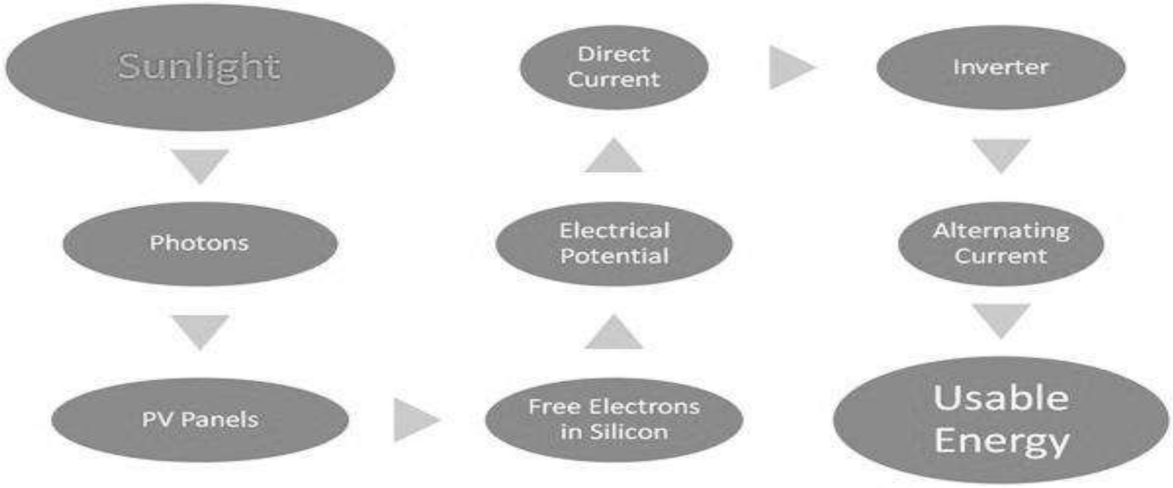

Figure 19: Process of Electricity Production from a PV System (Solar Works, 2012)

Types of PV systems

PV systems can be classified according to several factors, such as the systems application, operational requirements, component configurations, and the way in which the components are connected to power sources and electrical loads. Currently, two main types of solar PV systems are used: the standalone off-grid and the grid-connected or grid-tied solar PV system (Goetzberger & Hoffmann, 2005).

Stand-alone off-grid PV system is designed to work independently, and thus not connected to the electricity grid. It needs a battery bank to store the electricity that it produces. As such, this type of system is mostly used in areas located far from the electricity grid (Kaundinya, Balachandra, & Ravindranath, 2009). Figure 20 depicts an off-grid PV system.

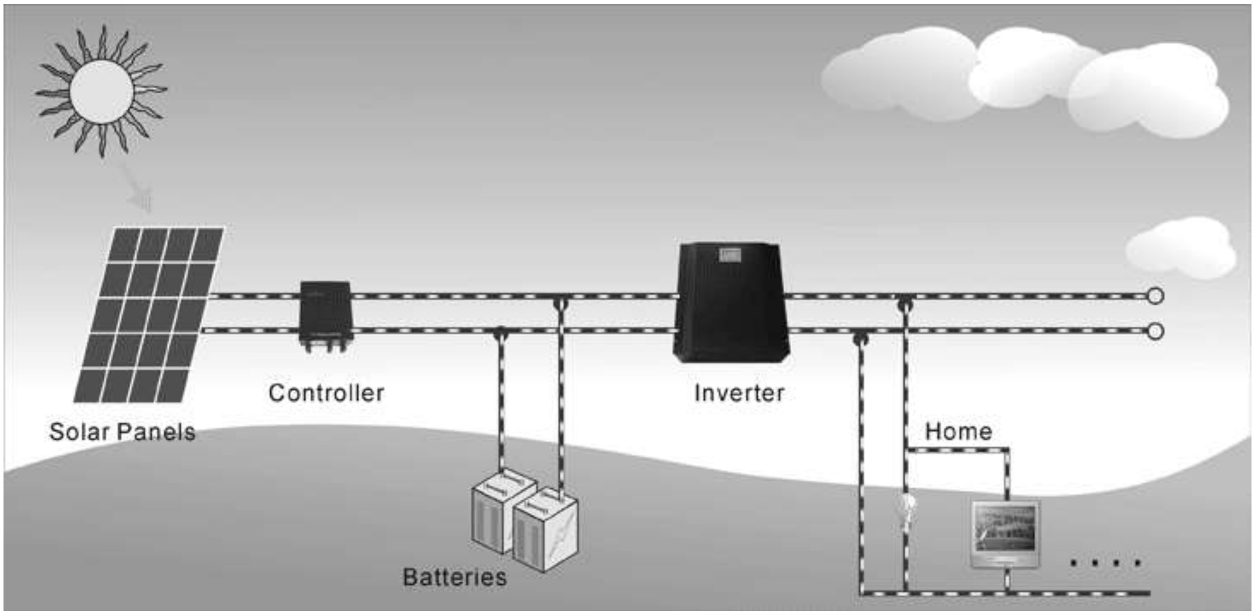

Figure 20: The Off-Grid PV System (Solartech Solutions, 2010).

In contrast to an off-grid PV system, a grid-connected PV system is designed to function in parallel with the electricity grid. While it is less expensive than an off-grid PV system because it does not require a battery bank, it does not provide backup power during a power outage, even if the sun is shining; however, for sites with a reliable grid power, this type of system is usually the logical choice (Aladdin Solar, LLC, 2008). Having no battery bank, the electric utility buys the electricity produced by a PV system through a system called net-metering.

The goal of installing a grid-connected PV system is to reduce the amount of, or even eliminate, the electricity and power that a resident consumes from the electric utility grid (Krigger & Dorsi, 2008). If the system produces more electricity than a household needs, the unused electricity will be returned to the utility grid, and the electric utility will pay the retail rate for it to the system owner (IN.GOV, 2002). This type of PV system is examined in this study because it is the cost effective type of system and other reasons mentioned in chapter 1 (Krigger & Dorsi, 2008). Figure 21 depicts a grid-connected PV system.

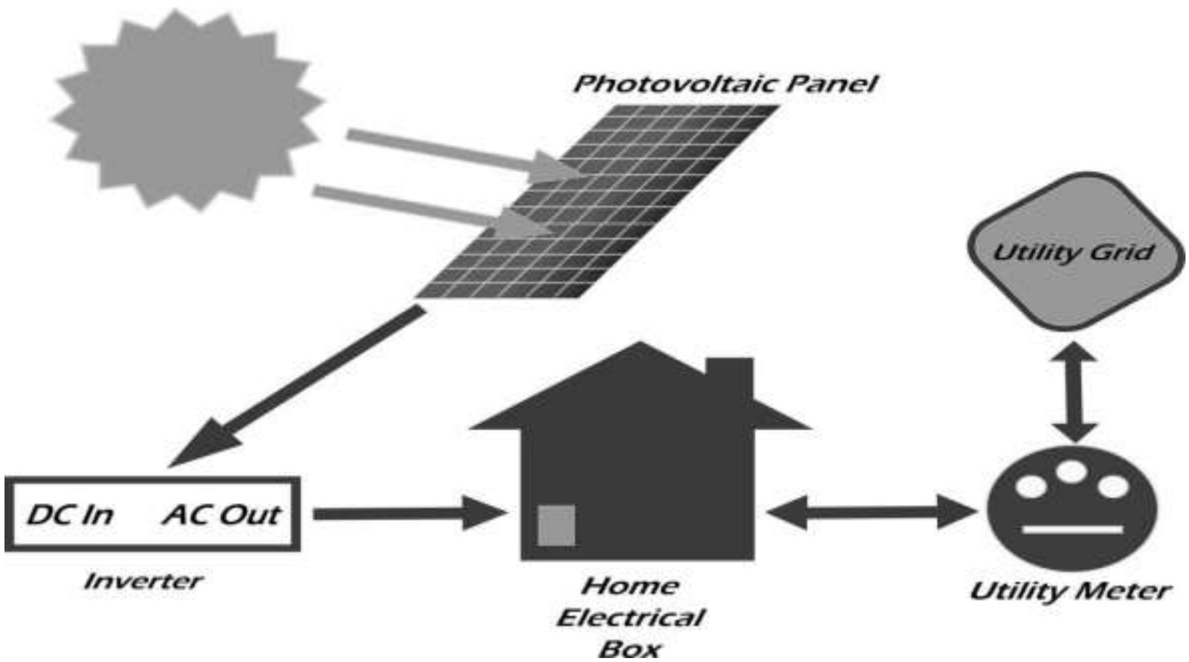

Figure 21: A Grid-connected PV System (Simplexsolar, 2010)

The Performance of Grid-Connected PV Systems

A Grid-Connected PV system consists of multiple modules wired together with an inverter that transforms the DC electricity produced by the PV modules into AC electricity. Some electricity loss occurs during the absorption and transformation process. The advanced technologies help PV manufacturers increase the average maximum efficiency of inverters. For example, the inverter efficiency was 95.5% in 2008 compared to 94.7% in 2005 (Knoll & Kreutzmann, 2008).

The nature of this study requires accurate prediction of decreased power output over time. Factors must be known in order to predict power delivery. According to the U.S. Department of Energy, the PV system's efficiency could be reduced due to factors include dirt and other materials obscuring sun-collecting surfaces, electrically mismatched modules in an array, wiring losses, and high cell temperatures. The NREL's PVWatts, a performance calculator for on-grid PV systems, uses an overall derate factor of 0.77 as a default, with the inverter component of this derate being 0.92.Table 11 lists the parameters of the derate factors that are used by the PV Watt calculator and their ranges.

Another important factor affects the PV system's efficiency is the system age factor or the degradation rate. Higher degradation rate means less power produced using the system and, therefore, reduces the future cash flows for the system. An analytical review study conducted by the U.S. Department of Energy found that the majority (78%) of literature during the last 40 years reported a degradation rate of less than1% per year (U.S. Department of Energy, 2012). Other studies estimate the degradation rate to be equal to 3% per year ((Energy Efficiency & Renewable Energy, 2008; El–Bassiouny & Mohamed, 2012; Jha, 2010). In order to decrease the financial risk and produce a high reliable result, this dissertation considers the higher value (3 % per year) as the degradation rate.

PV Systems in the United States

Among other solar systems, PV systems are the most common technology for residential generation (Solar Energy Industries Association, 2013). The process of installing PV systems in the U.S. has increased rapidly over the last ten years, from 4 MW in 2000 to more than 3,900 MW at the end of 2011. The main reason behind this rapid growth is that the U.S. government has established many initiatives to encourage residents and industries to use solar renewable energy. Such initiatives include state and federal financial incentive programs and state renewable portfolio standards (RPS) (NREL, 2012). Figure 22 shows the cumulative installed grid-connected PV in the U.S since 2000.

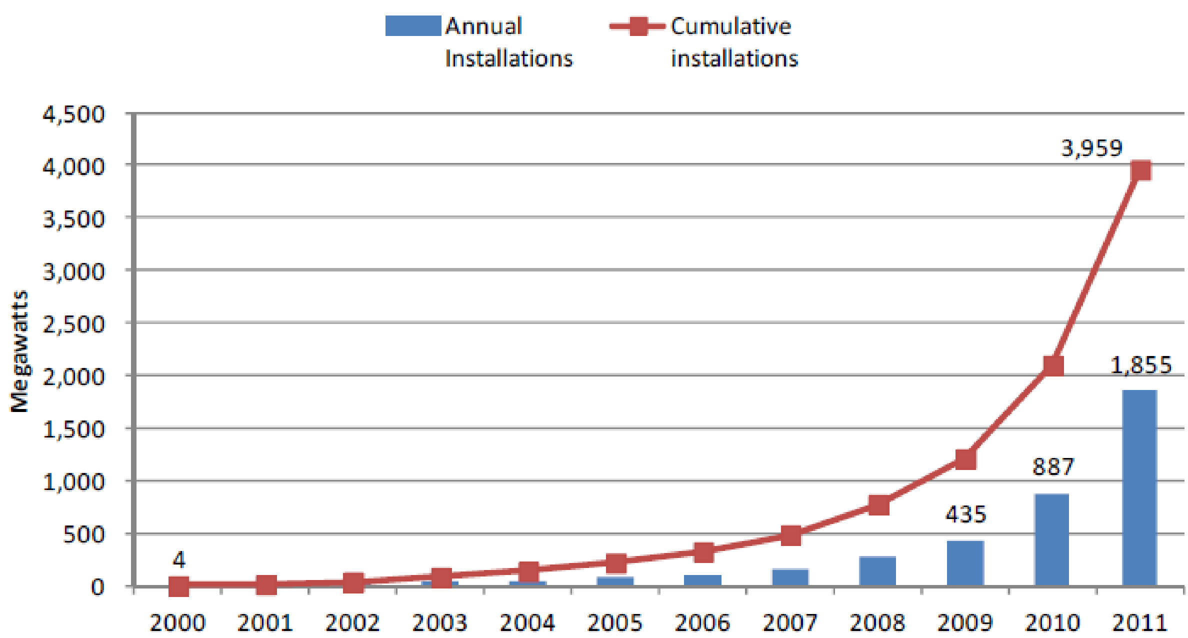

Figure 22: The Cumulative Installed Grid-Connected PV in the U.S (Solar Energy Industries Association, 2011).

PV Systems in the State of Indiana

Indiana has also experienced rapid growth in the number of PV systems installed because of the federal, state and utility incentives. About 80 percent of the systems were installed in 2011 (Purdue University, 2012). Currently, the Fort Harrison Federal Compound PV project, in Indianapolis, is the largest PV system in Indiana with capacity of 2,010 kW, followed by the Metal Pro Roofing Corporation of Franklin City in Johnson County with capacity of 186 kW. The third place is for the Johnson Melloh laboratory with size of a 100 kW (Purdue University, 2012). In the near future, the largest project will be at the Indianapolis Airport with capacity of 10 MW (Indianapolis Airport , 2011).

Federal Incentives for PV systems

As discussed earlier, the state and federal incentive programs are the main reason for the rapid growth in the PV sector. The incentive programs encouraged the public and the private sectors in the state of Indiana to install PV system. The federal government provides these incentives through the following programs:

- Energy Investment Tax Credit (ITC) incentive allows system owner to receive tax credits up to 30 percent of solar system costs.
- Energy Efficiency Mortgage program provides homeowners loans that can be used to finance a variety of renewable energy technologies including PV systems.
- Renewable Energy Production Incentive (REPI) provides nonprofit organizations with financial incentive for electricity produced and sold by renewable energy.
- Others: Modified Accelerated Cost-Recovery System (MACRS), Qualified Energy Conservation Bonds (QECBs), Residential Energy Conservation Subsidy Exclusion, Rural Energy for America Program (REAP), Value-Added Producer Grant Program, and High Energy Cost Grant Program (Database of State Incentives for Renewables and Efficiency, 2013).

State of Indiana Incentives for PV Systems

Indiana decision makers have made valuable efforts to increase the use of renewable energy from a variety of sources, including wind, solar, hydroelectric, and biomass sources. Part of their plan for developing the renewable energy infrastructure is offering incentives to Indiana residents, schools, and businesses to install renewable energy technologies. The state government provides these incentives through the following programs:

- Net-Metering Program: it requires investor-owned utilities (IOU) in Indiana to buy back unused electricity from Indiana residents at the same retail price that the IOU charges per kilowatt hour (Indiana Utility Regulatory Commission, 2012). There is a limit of 1 MW for the maximum capacity of net metering and the net excess generation is credited to the system owner in the next billing cycle (IN.GOV, 2012).
- Feed-in Tariff Program: a program designed to create policies that accelerate and encourage investment in renewable energy systems. The goal of this program is to offer long-term contracts to renewable energy producers and based on the cost of generation of each technology. For example, the energy generated by solar PV is offered for a higher price, reflecting higher costs. This program is offered by two companies Indianapolis Power & Light Co. and Northern Indiana Public Service Company.
- State of Indiana Property Tax Exemption Program: Indiana offers a state property tax deduction for the installation of solar technologies (IN.GOV, 2012). The state tax deduction is not considered in the study due to the lack of information regarding the amount of the deduction;
- Small Scale Renewable Energy Incentives Program is offered by Indianapolis Power & Light Co for installing residential and small-business PV systems that are between 1kW and 19.9 kW. The utility pays the system owner $2 per watt up to $4,000.
- Others: Emissions Credits, Solar Access Laws, and Clean Energy Portfolio Goal (Database of State Incentives for Renewables and Efficiency, 2013).

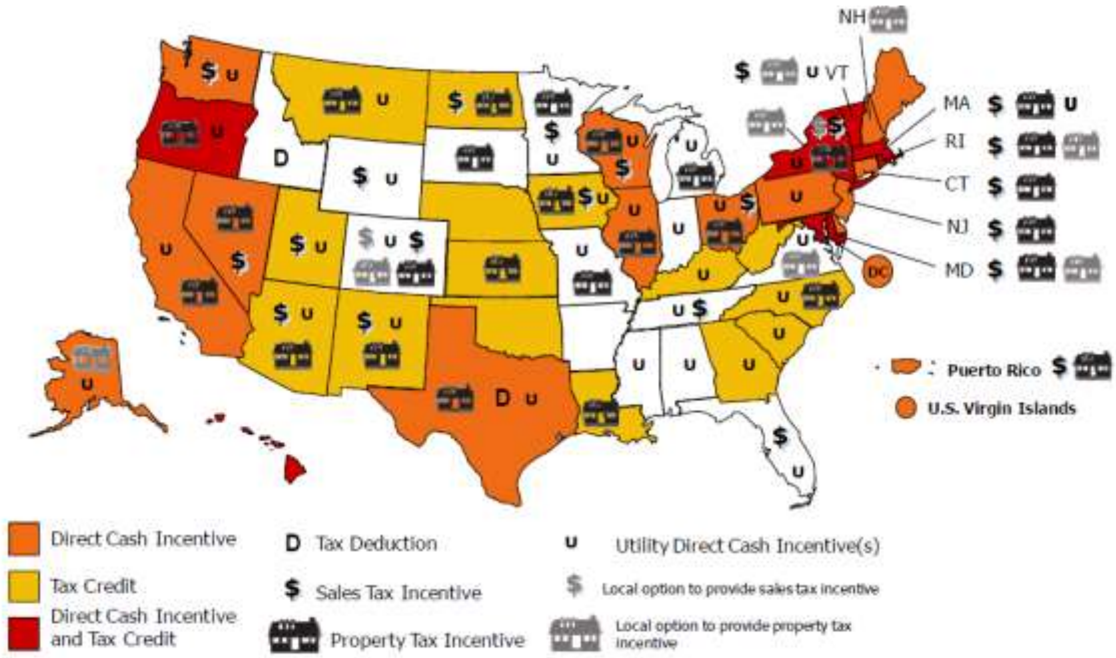

Figure 23: Financial incentives for solar-photovoltaic systems in the United State (Database of State Incentives for Renewables and Efficiency, 2013)

Indiana Electric Companies

According to the official website of the State of Indiana (IN.GOV, 2012), the following nine providers provide electricity to the residents of Indiana at different rates:

- Duke Energy Indiana (Formerly Cinergy/PSI)
- Hoosier Energy
- Indiana Michigan Power (a division of AEP)
- Indiana Municipal Power Agency
- Indiana Statewide Association of Rural Electric Cooperatives
- Indianapolis Power and Light
- Northern Indiana Public Service Company (NIPSCO)

- Vectren (formerly Southern Indiana Gas and Electric Company)
- Wabash Valley Power Association

Electricity Usage and Rates in the State of Indiana

According to the Electric Consumer Organization, “The average single-family home in Indiana consumes approximately 11,000 kWh per year” (Electric Consumer, 2011; US Energy Information Administration, 2012) at an average rate of 7.52¢ per kWh plus a 7% state tax for electricity usage (IN.gov, 2013). According to a research project conducted by Purdue University (2012), the residential rate is projected to increase 12% every year on account of three factors: “costs associated with ongoing new plant construction, costs associated with extending the life of existing generating facilities, and costs associated with meeting environmental rules” (Purdue University, 2008; Indiana Utility Regulatory Commission, 201; IN.gov, 2012).

Since the new regulations are not yet in effect, this study only considers the real increase in electricity prices during the period between 2005-2011 without considering the impact of the new EPA regulations. Table 1 shows the average electric rates in the State of Indiana between 2005 and 2011. Also, from the table, it can be found that the average increase in electricity rates is 1.052%. This rate is used in this study to measure the impact of future increase in electricity prices on the economic performance for the standard PV system.

Table 1

The Average Electric Rates in the State of Indiana, 2005-2011 (U.S. Energy Information Administration, 2012).

Year	Price (Cents/KWh)	The increase
2005	7.5	
2006	8.22	1.096%
2007	8.26	1.01%
2008	8.87	1.074%
2009	9.5	1.07%
2010	9.56	1.01%
2011	10.06	1.05%
The average increase		1.052 %

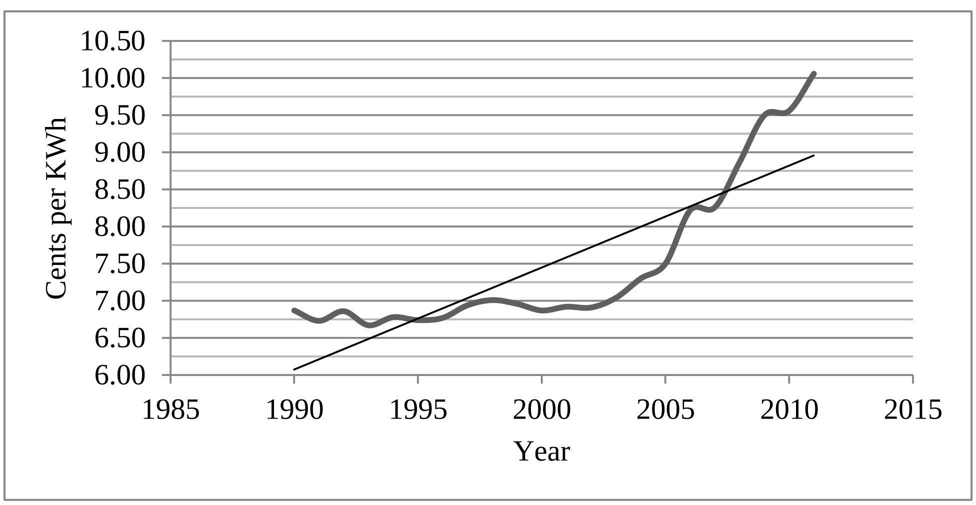

Figure 24: The Average Electric Rates in the State of Indiana, 1990-2011 (U.S. Energy Information Administration, 2012)

The Energy Efficiency and Renewable Energy Clearinghouse (2012) estimates the average yearly energy consumption for a typical home according to the 23 appliances described in Table 2.

Table 2

The Average Energy Consumption for a Typical Home (Energy Efficiency and Renewable Energy Clearinghouse, 2012)

Appliance	Time in use	kWh / year
Air Conditioner (one ton)	4 hrs / day, 180 days/ yr	2278
Clock radio	24 hours / day	44
Clothes washer (does not include hot water)	2 hours / Week	31
Coffee maker	30 minute / day	128
Dehumidifier	12 hours / day	700
Dishwasher (does not include hot water)	1 hour / day	532
Electric blanket	8 hrs / day,120days / yr	175
Fan (furnace)	12 hrs / day,120 days / yr	432
Fan (whole house)	4hrs / day, 120 days / yr	270
Fan (window)	4 hrs / day,180days / yr	144
Hair dryer	15 minutes / day	100
Heater (portable)	6 hours / day,120 days / yr	1240
Iron	1 hour/week	52
Microwave oven	2 hours/week	89
Radio (stereo)	2 hours / day	73
Range (with self-cleaning)	2 hours/ day	775
Refrigerator (frost free 16 cubic feet)	24 hours / day	642
Television	4 hours / day	292
Toaster	1 hour / day	73

Appliance	Time in use	kWh / year
Vacuum cleaner	1 hour / week	38
VCR	4 hours / day	30
Water bed (no cover)	12 hrs / day,180 days / yr	620
Water heater (40 gallon)	2 hrs / day	2190
	Total	10948

Engineering Economics

Engineering economics is a subset of the economic sciences that focuses on the viability of engineering applications and solutions. An important concept in engineering economics science is the time value of money, the difference in value between having a dollar in hand today and receiving a dollar at some future time (Newnan, Eschenbach, & Lavelle, 2011). Of the various concepts of engineering economics were used in this study, the most important is cash flow, the movement of money in or out of a project. Tracking the cash flow helps business owners determine the number of years required to return the share capital of a project. Another important concept that was used in this study is the net present value, the value of a payment or series of payments made at other times.

Engineering Cost and Economic Analysis for a PV system

Investment in a PV project involves several cash flow streams that should be economically assessed based on a consistent measure. Column diagrams can be used to show these cash flows streams. The purchase cost and maintenance costs are shown as negative cash flow, while the value of the electricity produced and other income/saving values (e.g., salvage value, profit) are shown as positive cash flow value (Whisnant, Johnston, & Hutchby, 2003).

For a PV system, the value of the generated electricity is considered as an inflow-positive cash flow value. This value is usually determined by the avoided expense of the electricity that would otherwise need to be purchased from the utility company (Al-Odeh, Stergioulas, & Badar, 2012).

In order to determine whether a PV project is viable, the summations of costs and benefits should be evaluated at a selected point in time, usually the present time. The summations are called the present value or the present worth of the systems. Any money received or spent at the present time has a present worth, P. Any money received or spent at a future time during *n* years hence has a future worth, F. If amount of money P is invested at a present time with an interest rate of *i* percent per year, then its future worth at the end of n years is

$F = P\,(1 + i)^{n}$ ………………………………………………………………………… Equation 1

The present worth of a future sum is given by

$P = F\,(1 + i)^{-n}$ ………………………………………………………………………… Equation 2

Equation 2 shows that the present worth of a sum received n years in the future is reduced by the factor $(1 + i)^{-n}$.

In a PV system investment, the interest rate *i* is referred to as a discount rate which is defined as "the value that the system owner puts on the capital invested in the system, and is often called the opportunity cost of the investor; that is, the rate of return foregone on the next most attractive investment" (Whisnant, Johnston, & Hutchby, 2003).

The cash flows for a PV investment should include energy savings, equipment costs, replacement, maintenance, and other related inflows or outflows values. The cash flow at year 0 is the initial cost of the system plus the installation cost. The cash flow (CF) at the end of the first year is the savings due to electricity generation multiplied by the state sales tax. The cash flows for the remaining years have been computed by multiplying the cash flow for the previous year by the yearly percentage of increase/decrease in electricity cost.

If a positive cash flow value (e.g. salvage value) occurs during the system lifetime, this income/saving value should be added to the cash flow of that year. On the other hand, if a negative cash flow value (e.g. replacement of equipment) occurs, this expense value should be subtracted from the cash flow of that year.

Cash flow is also important for calculating the project balance and the discounted payback period (DPP), which considers the time value of money for the system. DPP is defined as the number of periods until the compounded sum of net revenues equals the compounded value of the initial cost.

The project balance (PB) for the year 0 is equal to the cash flow for year 0, which is equal to initial cost and the installation costs. For the remaining years, it can be calculated by multiplying the project balance of the previous year (t-1) by the interest rate (i) and adding cash flow of that year (t).

$PB_t = [PB_{t-1} * (1+i)] + CF_t$ …………………………………………………………… Equation 3

Project balance (PB) helps to determine the discounted payback period (DPP). The DPP over 25 years has been calculated along with the internal rate of return (IRR) and the net present value (NPV) or present worth (PW). IRR is the interest rate (i*) at which the project benefits are equivalent to the project costs or the present worth (PW) of the project is zero. IRR (i.e., i*) can be obtained by solving Equation 4 for i*:

$$PW(i^*)=0=PW(i^*)_{\text{benefit}}-PW(i^*)_{\text{cost}}=\sum_{t=0}^{n} CF_t(1+i^*)^{-t} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 4}$$

IRR can also be computed from a range of cash flows (from period 0 to n) using the IRR function in the Microsoft Excel as given below (Newnan, Eschenbach, & Lavelle, 2011).

IRR:=IRR(values, [guess]) ……………………………………………………………Equation 5

NPV or net PW or PW represents an equivalent amount of the project cash flows at t = 0 (i.e., present time) at interest rate (i). PW (i) can be obtained using Equation 6 (Newnan, Eschenbach, & Lavelle, 2011):

$$NPV(i)=PW(i)=PW(i)_{\text{benefit}}-PW(i)_{\text{cost}}=\sum_{t=0}^{n} CF_t(1+i)^{-t} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 6}$$

NPV can also be computed from a range of cash flows (from period 1 to *n*) using the NPV function in the Microsoft Excel as given below (Newnan, Eschenbach, & Lavelle, 2011).

NPV:=NPV(rate, values) ………………………………………………………………Equation 7

If any cash flow occurs at n=0, it is added algebraically to the value obtained from Equation 7.

Previous Research into PV System Economic Feasibility

This section provides the reader with research evaluating the financial analyses for PV systems, starting with Ayton (2006). He believes that there is a lack of communication between lending institutions, the solar PV industry, and consumers. Such a gap in communication between these different parties has resulted in the inability to measure the market value of a PV system caused by:

- The lack of documentation of the financial electricity savings value of PV systems.
- The economic outcome of a PV system is not guaranteed due to fluctuations in energy prices.
- The lack of tools that help lending institutions design loan programs for energy systems.

Consequently, the author argues that these reasons may discourage homeowners from investing in PV systems. Ayton further asserted that, in order to shrink this communication gap between homeowners, lenders, appraisers, and solar installers, efforts should be spent on:

- Simplifying PV terminology and creating standard descriptions for non-experts.
- Making bankers aware of how PV systems work by showing them examples of the cash flows of existing and new PV systems.
- Collecting actual data for PV systems' performance so bankers will be able to design contemporary loan programs for energy systems.

Another study, supporting Ayton's argument, was conducted by Farah (2008), who collected and analyzed data from 306 homes and a comparison group of 103 similar homes located in a similar area. The homes with PV, ranging from 2,600 to 3,376 square feet in size, were all connected to the grid. This study concluded that the cost of solar PV was higher than the market valuation of the power it produced; thus, solar PV did not compete on a cost basis with competitive energy sources.

Other studies used financial parameters to evaluate PV systems. For example, Black (2009) described four economic methods for calculating the economic viability for residential PV systems: rate of return, payback period, property value increase, and cash flow when financing. Black's report provided examples of project costs and savings, including the resale value return, in order to demonstrate the financial returns from the application. For example, Black showed that ROIs of the 9kWh PV system is 223 % (highest return).

Other studies have been conducted in other locations around the world. For example, Shaahid and Elhadidy (2007) investigated the economic viability of a commercial hybrid photovoltaic system with a capacity of 80kWh in the Kingdom of Saudi Arabia (KSA). The researchers used NREL's HOMER simulation software, finding that the cost of generating to be 0.149 $/kWh, higher than the retail prices in KSA.

In Spain, Bernal-Agustín and Dufo-López (2006) measured the economic and environmental benefits of a grid-connected PV system with capacity of 1 kWh. The researchers used economic parameters to determine the viability of a PV installation including net present value and pay-back period analysis. The economic analysis shows that, given current prices, investment in a grid-connected PV system is profitable although the payback period is more than nine years.

Similar studies have been conducted in Egypt by El-Kordy et al. (2002), who examined the PV plant with a 3.3 MW scope as well as the costs of externalities of emissions from different generating systems in electricity generation. They concluded that photovoltaic systems are not justified economically in Egypt, and the cost of the system needs to be reduced by 60% in order to be economically competitive.

Another study was conducted in Israel by Garb and Friedman (2008), who aimed to measure the financial viability of a 4kWh private system, and of two commercial systems of 50kWh, both with and without two-axis tracking. The researchers considered the advantages of feed-in tariff programs, using payback period, net present value, and internal rate of return for the systems. The analysis showed that the smaller system has a payback period of 16 years and a NPV of only 17,220 NIS. The larger system had a payback period of 16 years and a NPV of 138, 819 NIS. The system with two-axis tracking gives a NPV of 307,533 and a payback period of 13 years. The research concluded that all such systems are economically justified.

In Bangladesh, the potential of a proposed 1-MW grid-connected solar PV system was estimated by Mondal and Islam (2011). The researchers used NASA solar radiation data and HOMER optimization software, estimating the performance for the system in 14 locations in Bangladesh. Several different economic and financial factors were considered including the internal rate of return, net present value, benefit-cost ratio, cost of energy production, and simple payback. The result of the research showed that the system has favorable conditions for developing the proposed PV system in any location.

In the United States, the National Renewable Energy Laboratory (NREL) in partnership with the Environmental Protection Agency (EPA) conducted several studies related to the financial viability for PV systems. One study investigated the feasibility of the economics and performance of three different PV systems: crystalline silicon (fixed tilt), crystalline silicon (single-axis tracking), and thin film (fixed tilt) in St. Marks, Florida. Two locations were considered in the study. The researchers analyzed the data based on electric rate of $0.08/kWh, and they considered incentives offered by the State of Florida and from two local utility companies. The research found that both locations were suitable for incorporating PV systems (National Renewable Energy Laboratory, 2010).

Another study conducted by the NREL and the EPA in Massachusetts to assess sites within a landfill area for suitability of potential solar photovoltaic (PV) installations estimated the cost, performance, and site impacts of the different PV systems. The analysis was based on crystalline silicon PV systems in four locations. The researchers used an electric rate of $0.159/kWh and considered incentives offered by the Commonwealth of Massachusetts. The conclusion for the research was that the four locations were suitable to incorporate PV systems (National Renewable Energy Laboratory, 2011).

A third study conducted by the NREL and the EPA in Middleton, Wisconsin, assessed the Refuse Hideaway Landfill for possible PV installation. The researchers used three different PV options: crystalline silicon (fixed tilt), crystalline silicon (single-axis tracking), and thin film (fixed tilt). The economics analysis was conducted by considering an electric rate of $0.1333/kWh and incentives offered by the local utility company, the State of Wisconsin, and the 30% federal tax credit. The study found that all three systems were viable economically and the payback period range would be from 17-25 years (National Renewable Energy Laboratory, 2011).

Another study conducted in Nitro, West Virginia, by the NREL and the EPA to measure the economic benefits of three different PV options: crystalline silicon (fixed-tilt), crystalline silicon (single-axis tracking), and thin film (fixed-tilt) in eight locations around Nitro, WV. The analysis based on an electric rate of $0.08/kWh also considered incentives offered by West Virginia and the local utility company. The study concluded that all the locations were suitable for PV systems (National Renewable Energy Laboratory, 2010).

Another study conducted for NREL (1999) aimed to investigate the viability for high-value photovoltaic technology options for four U.S. environmental protection agency facilities located in Pensacola, FL; Ada, OK; Ann Arbor, MI; and Duluth, MN. The study found the systems are viable economically and the payback period ranges from 13-16 years (National Renewable Energy Laboratory , 1999).

In the Commonwealth of Puerto Rico, a study was conducted by the NREL and the EPA to assess the performance and the cost of three types PV systems in eight locations. It found that the payback period ranged from 5 to 31 years. Moreover, in the future, increasing electrical rates will continue to improve the feasibility of installing PV systems in Puerto Rico (National Renewable Energy Laboratory, 2011).

Last, but not least, a study investigated the economic performance of residential solar systems (photovoltaic and water heating) in Michigan and Hawaii. The study found that a residential 2.4 Kwh grid-connected PV system is not attractive economically in Michigan under net metering; however, in Hawaii the researcher considered the system a reasonable investment (Richter, 2009).

Table 3

Summary of Previous Research related to PV System Economic Feasibility

Author (year)	Location	Eng. Econ. Measures	Conclusion
Ayton (2006)	San Mateo, CA	Cash Flow	Bankers should be aware of PV cash flows. More studies should be conducted on the PV cash flow.
Farah (2008)	United States	Cash Flow	The cost of solar PV was higher than the market valuation
Black (2009)	CA	ROI, rate of return, payback period, property value increase, and cash flow	The ROI's of the 9kWh PV system is 223%
Garb and Friedman (2008)	Israel	NPV and pay-back period analysis	The larger system had a payback period of 16 years. The system with 2 axis tracking gives a NPV of 307,533 and a payback period of 13 years.
Bernal-Agustín and Dufo-López (2006)	Spanish	NPV and pay-back period analysis	The PV systems is profitable and the payback period is more than nine years
El-Kordy et.al (2002),	Egypt	NPV and pay-back period analysis	The photovoltaic systems are not justified economically in Egypt and the cost of the system needs to be reduced by 60% in order to be economically competitive.
Shaahid and Elhadidy (2007)	Kingdom of Saudi Arabia (KSA).	payback period, property value, and cash flow	The system is not viable at this time

Author (year)	Location	Eng. Econ. Measures	Conclusion
Mondal and Islam (2011)	Bangladesh	net present value and pay-back period analysis	The system has favorable condition for development in the country.
NREL (2010)	St. Marks, Florida, United States	Cost analysis	The research found that both locations were suitable to incorporate PV systems
NREL (2010)	Massachusetts	Cost analysis, payback	The conclusion for the research was that the four locations are found suitable to incorporate PV systems
NREL (2011)	Middleton, Wisconsin	Cost analysis, payback	The study found that all three systems are viable economically and the payback period rage is from 17-25 years
NREL (2010)	Nitro, West Virginia	Cost analysis, payback	All the locations were found suitable for PV systems
NREL (1999)	Pensacola, FL; Ada, OK; Ann Arbor, MI; and Duluth, MN	Cost analysis, payback	The systems are viable economically and the payback period ranges from 13-16 years
NREL (2011)	Puerto Rico	Cost analysis, payback	The system payback period range from 5 to 31 years
Richter (2009)	Michigan and Hawaii	NPV, IRR, Cash flow	The PV system is not attractive economically in Michigan; while in Hawaii the researcher consider the system as a reasonable investment

Summary

This chapter reviewed the literature regarding renewable energy to provide understanding of the concepts and findings that guided this study. After discussing the types of renewable energy available, it described the generation of renewable energy via a PV system, the focus of this study, by explaining the components and functioning of this system. It then reviewed the data regarding the current sources of electricity generation in the State of Indiana and the progress, and lack thereof, of increasing renewable energy generation to explicate the challenges of encouraging greater PV system use in the state. After explaining the engineering economics concepts that are used to conduct PV system feasibility analysis, the chapter concluded by discussing the findings of previous research regarding the feasibility of renewable energy generation at sites throughout the world.

CHAPTER THREE

METHOD OF INVESTIGATION

Evaluation of the financial feasibility of installing and using a renewable energy system requires the collection and analysis of data and evaluation of the results thereof using mathematical models and formulas. This chapter describes and provides justification for the use of the methods, models, and instruments that were used in this evaluation of the financial feasibility of installing and using a standard residential PV system in the State of Indiana. It also explains the procedures employed, and specifies the minimum requirements that the study must meet. In addition, a description of the designing tools that were used in the study has been provided.

Description of Procedures

This study has employed a systematic approach to collect data via reviewing the relevant literature, requesting information about the system's cost from PV professionals, collecting data about the Indiana cities from the State of Indiana website, using a computer simulation program called PV Watt Calculator, which is launched and developed by the U.S. Department of Energy, to estimate a standard system's performance, and then evaluating the collected data using several applications that yield reliable and valid results. The review of the literature has been conducted to provide understanding of PV technologies and determine the ideal sites for installing standard

PV systems and the questions to ask PV professionals, as well as to collect data regarding the size, components, and costs associated with installing a PV system suitable for a typical single family home in Indiana.

After the data have been collected, the analysis process began with calculation of the potential amount of electricity produced by a standard PV system. This calculation followed by application of engineering economic methods and applications based on several concepts, including breakeven, cash flow analyses, net present value, and internal rate of return, to determine the economic features of the system. Finally, the results of the analysis were used for answering the following study questions:

10. What is the precise size of a PV system suitable for a typical single family home in Indiana?
11. How much does a standard PV system cost?
12. How much electricity will a standard PV system produce?
13. By how much will a standard PV system reduce electricity expenses?
14. Is the standard PV system, without government subsidy support, financially attractive investments to Indiana homeowners?
15. Does the Federal tax credit make it a good investment?
16. What is the payback period for a standard PV system?
17. What is the internal rate of return for a standard PV system?
18. How will future electric rate increases impact financial metrics, specifically internal rate of return?

The specific objectives of the study:

8. To determine the suitable and standard size of a residential PV system for average Indiana households.
9. To estimate the energy generation of a standard PV system and determine areas with high solar potential.
10. To gain understanding of the economic benefits of using a standard PV system.
11. To identify the factors that should be considered when determining the economic payoff of installing and using a PV system in terms of electricity rate, system performance, and incentives.
12. To use US Department of Energy recommendations and methodologies to develop a model for building a standard PV system.
13. To evaluate the current policies toward installing a standard residential PV system in the state of Indiana.
14. To determine the areas suitable for installing a commercial PV system in the State of Indiana.

Description of Subjects and Equipment

The study utilized the following methods, tools, and applications:

PV Watts application: The PV Watt is a computer simulation application developed by the U.S Department of Energy to predict the energy production and cost savings of grid-connected photovoltaic (PV) energy systems throughout the world. “It allows homeowners, installers, manufacturers, and researchers to easily develop estimates of the performance of hypothetical PV installations” (NREL, 2012). This application was the most important application used in this study because it was used to estimate the electricity that could be produced by a standard PV system.

The latest version (version 2) of the PV Watts was used in this study. This application is Internet accessible. The user selects the location from an electronic map or by entering the azimuth and latitude. The nearest station (TMY) that is climatically similar was selected by the application. Then, an hourly performance simulation for the station was conducted. The system performance was based on differences in solar radiation and temperature using previously determined data grid sets of monthly solar radiation and maximum daily temperature. The system performance was calculated by determining the DC power:

$$AC_{dg} = \frac{E_{dg}}{E_{TMY}} \cdot \left[1 + \gamma \cdot \left(T_{dg} - T_{TMY}\right)\right] \cdot AC_{TMY}$$ ……………………………………………….. Equation 8

Where: E_{dg} = plane-of-array (POA) irradiance, W/m2; $E_{TMY} = E_{TMYdn} + E_{TMYsky} + E_{TMYrefl}$; E_{TMYdn} = Monthly direct beam component of POA; E_{TMYsky} = Monthly diffuse sky component of POA ; $E_{TMYrefl}$ = Monthly ground reflected component of POA; Tdg = Monthly average daily maximum dry bulb temperature for data grid cell; T_{TMY} = Monthly average daily maximum dry bulb temperature for reference TMY2 site; AC_{TMY} = Monthly AC energy production calculated for reference TMY2 site; and γ = Pmp correction factor for temperature = -0.005°C-1; (Marion, Anderberg, George, Gray-Hann, & HeimillerD., 2001).

Google Earth: Google Earth is an application that provides geographical information regarding locations. This application was used to determine the solar azimuth and solar altitude, two important variables that were used in the PV Watt application to estimate the potential power that could be produced through use of the standard PV system.

Microsoft Excel: Microsoft Excel is a software package used to produce spreadsheets and graphs and perform mathematical functions and calculations. It was used in this study to calculate important financial concepts, including cash flow, net present value, and internal rate of return, and present the results thereof in charts.

Online quoting: Via their websites, PV system providers were requested to provide online quotes of the size, necessary components and their costs, maintenance expenses, and lifetime of a standard single family residential PV system.

Smart Draw: Smart Draw is application that assists in the capture and presentation of information and results in the form of graphics.

Zip Code finder: The Zip Code Finder is a general web application offered by many websites to identify the zip code of a specific area for the counties in the State of Indiana.

Figure 25 summarizes the tools and the applications that were used in the study.

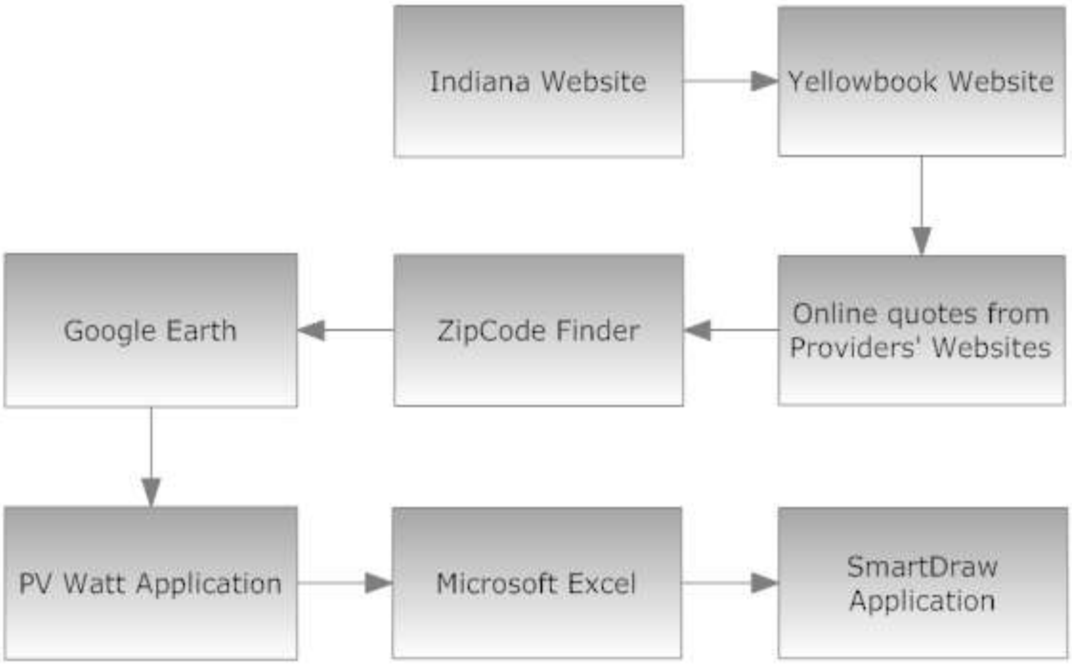

Figure 25: Research Tools and Applications

Research Design and Procedures

The first step in the research process was identifying the counties of Indiana and the regions into which they are grouped by accessing the official Government of Indiana website (IN.gov). Table 4 and Figure 26 show the counties in the State of Indiana. According to the Indiana website, the counties are grouped into the six geographical regions of North, East, West, Central, South Central, and South.

Table 4

Indiana Counties

North	East	West	Central	South Central	South
Elkhart	Adams	Benton	Boone	Bartholomew	Clark
Fulton	Allen	Carroll	Hamilton	Brown	Crawford
Jasper	Blackford	Clay	Hancock	Daviess	Dubois
Kosciusko	Cass	Clinton	Hendricks	Dearborn	Floyd
La Grange	De Kalb	Fountain	Johnson	Decatur	Gibson
Lake	Delaware	Montgomery	Marion	Franklin	Harrison
LaPorte	Fayette	Newton	Morgan	Greene	Orange
Marshall	Grant	Owen	Shelby	Jackson	Perry
Porter	Henry	Parke		Jefferson	Pike
Pulaski	Howard	Putnam		Jennings	Posey
St. Joseph	Huntington	Sullivan		Knox	Scott
Starke	Jay	Tippecanoe		Lawrence	Spencer
Steuben	Madison	Vermillion		Martin	Vanderburgh
	Miami	Vigo		Monroe	Warrick
	Noble	Warren		Ohio	Washington
	Randolph	White		Ripley	
	Rush			Switzerland	
	Tipton				
	Union				
	Wabash				
	Wayne				
	Wells				
	Whitley				

Figure 26: The State Of Indiana (IN.GOV, 2012)

The next step was sorting the counties within each group according to population and then selecting the county with the highest population within each group to represent the geographical region, as it is most representative of the greatest number of Indiana residents in that region. By using this procedure, it may be easier to target the most populous locations where the findings can be made known to the greatest number of residents, which will facilitate the study goal of increasing awareness of PV systems among the greatest number of Indiana residents possible.

Table 5 shows the populations of the counties in the North region as of July of 2011 (STATS Indiana, 2012). Based on its population, Lake County was selected to represent the North region.

Table 5

Populations of Counties in the North Region

Name	Population	Name	Population
Pulaski	13,363	Kosciusko	77,336
Fulton	20,872	LaPorte	111,374
Starke	23,199	Porter	165,537
Jasper	33,416	Elkhart	198,941
Steuben	34,028	St. Joseph	266,700
La Grange	37,382	Lake	495,558
Marshall	47,050		

Table 6 shows the populations of the counties in the East region as of July of 2011 (STATS Indiana, 2012). Based on its population, Allen County was selected to represent the East region.

Table 6

Population of Counties in the East Region

Name	Population	Name	Population
Union	7,513	Miami	36,611
Blackford	12,594	Huntington	37,211
Tipton	15,788	Cass	38,828
Rush	17,287	De Kalb	42,462
Jay	21,310	Noble	47,553
Fayette	24,285	Henry	49,264
Randolph	26,105	Wayne	68,643
Wells	27,734	Grant	69,793
Wabash	32,608	Howard	82,800
Whitley	33,392	Delaware	117,660
Adams	34,370	Madison	131,235
		Allen	358,327

Table 7 shows the populations of the counties in the West region as of July of 2011 (STATS Indiana, 2012). Based on its population, Tippecanoe County was selected to represent the West region.

Table 7

Population of Counties in the West Region

Name	Population	Name	Population
Warren	8,431	Owen	21,499
Benton	8,853	White	24,694
Newton	14,161	Clay	26,894
Vermillion	16,231	Clinton	33,104
Fountain	17,213	Putnam	37,917
Parke	17,237	Montgomery	38,441
Carroll	20,031	Vigo	108,182
Sullivan	21,356	Tippecanoe	174,724

Table 8 shows the populations of the counties in the Central region as of July of 2011 (STATS Indiana, 2012). Based on its population, Marion County was selected to represent the Central region.

Table 8

Population of Counties in the Central Region

Name	Population	Name	Population
Shelby	44,337	Johnson	141,656
Boone	57,481	Hendricks	147,979
Morgan	69,464	Hamilton	282,810
Hancock	70,529	Marion	911,296

Table 9 shows the populations of the counties in the South Central region as of July of 2011 (STATS Indiana, 2012). Based on its population, Monroe County was selected to represent the South Central region.

Table 9

Population of Counties in the South Central Region

Name	Population	Name	Population
Ohio	6,065	Jefferson	32,249
Martin	10,332	Greene	32,895
Switzerland	10,569	Knox	38,500
Brown	15,099	Jackson	42,966
Franklin	23,041	Lawrence	46,195
Decatur	25,944	Dearborn	50,113
Jennings	28,196	Bartholomew	77,870
Ripley	28,759	Monroe	139,799
Daviess	31,978		

Table 10 shows the populations of the counties in the South region as of July of 2011 (STATS Indiana, 2012). Based on its population, Vanderburgh County was selected to represent the South region.

Table 10

Population of Counties in the South Region

Name	Population	Name	Population
Crawford	10,658	Gibson	33,505
Pike	12,728	Harrison	39,336
Perry	19,354	Dubois	42,199
Orange	19,969	Warrick	60,275
Spencer	20,961	Floyd	74,989
Scott	23,987	Clark	111,570
Posey	25,720	Vanderburgh	180,305
Washington	28,147		

Figure 27 shows a coded-color map for the counties that represent the regions in the State of Indiana. The red County represents the Northern region, the blue County represents the Eastern region, the green County represents the Western region, the orange County represents the Central region, the pink County represents the South Central region, and the brown County represents the southern region.

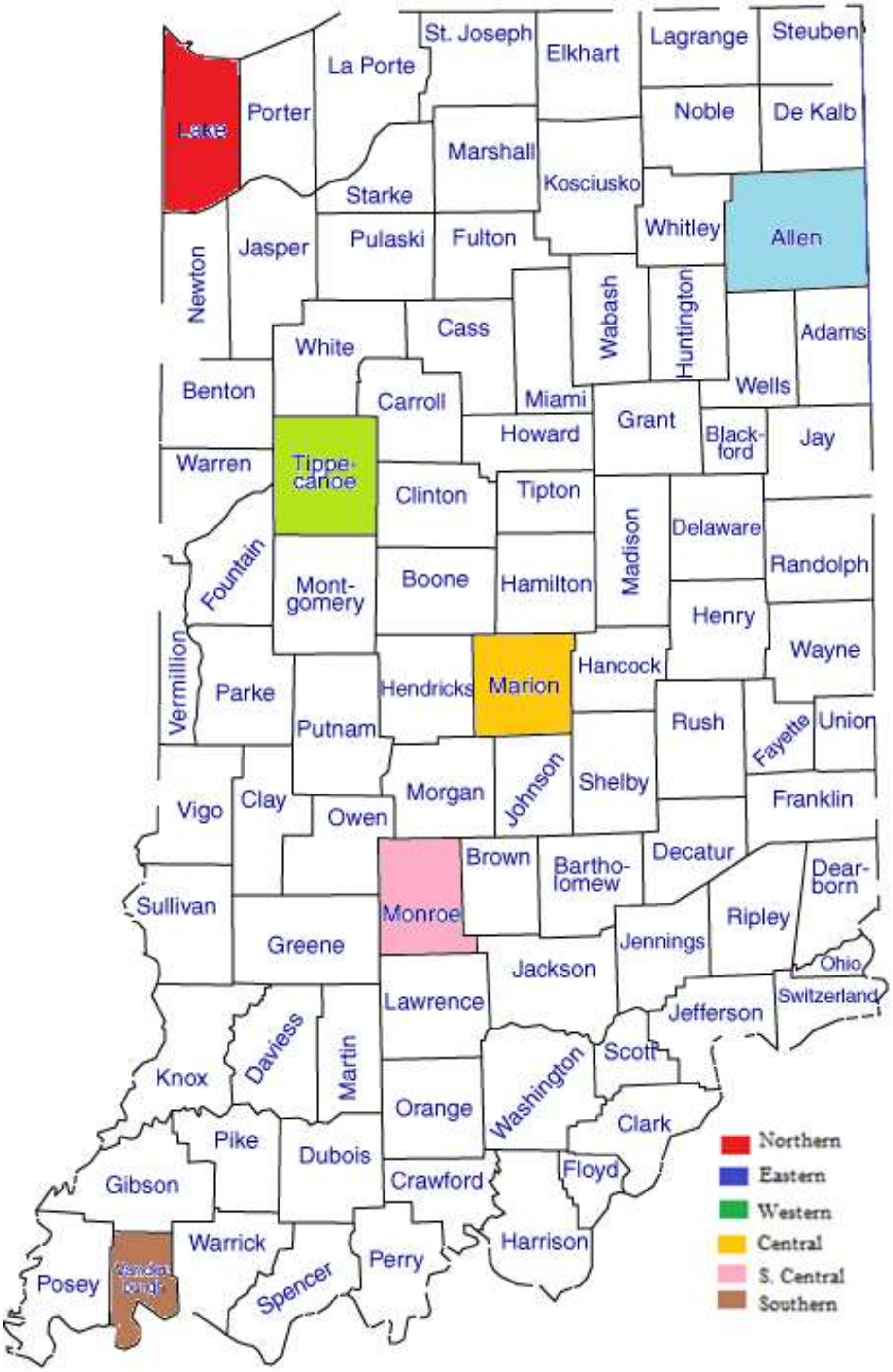

Figure 27: Color-coded Map for the Counties that were Included in the Study.

The third step was identifying the zip codes and the cities within each of the selected counties (regions of the state) using the Zip Code Finder application. The tables in Appendix A summarize the zip codes and the cities located in the selected counties. Identification of the zip codes for each city was important because the codes were used to collect precise geographical data, including solar power potential, that affect the amount of electricity that can be generated via a standard PV system located in a particular area.

The fourth step was using the Google Earth application to determine the solar azimuth and solar altitude, two parameters necessary to identify the exact locations for each zip code to determine the solar power potential for each area.

The fifth step was entering the geographical parameters and the data collected from PV professionals into the PV Watt application to calculate the amount of energy that can be produced using a standard PV system.

Data regarding the costs of installing a standard system was collected by requesting online quotes from PV professionals via their websites. The names and the websites of PV manufacturers, distributers, dealers, and repair specialists were identified using the key phrase "Solar System" and the location of "Indiana" to search the electronic version of the Yellow Book. The results were then filtered by selecting the following three categories:

1. Solar Energy Equipment and Systems–Dealers;
2. Solar Energy Equipment and Systems–Service and Repair; and
3. Solar Energy Equipment and Systems–Manufacturers and Distributors.

Table 40 in Appendix B summarizes the contact information for PV professionals in the State of Indiana.

The online quotes provided data regarding required components and their costs, size, maintenance costs, and expected lifetime, necessary to address the following questions:

A. Components and costs:
   1. What are the major components of a grid-connected PV system?
   2. What is the cost of each component and its installation, and on what basis is the cost determined?
B. Performance:
   1. How the electrical performance of PV modules and arrays is typically rated?
   2. How should a PV array be oriented for maximum energy production?
C. Size
   1. What is the surface area that is required for installing a PV array?
D. Maintenance
   1. What is the estimated annual maintenance cost of a standard PV system?
E. Lifetime
   1. What is the expected lifetime of a standard PV system?

As shown in Figure 28, the first step in using the application is entering the location and clicking the "Go" button.

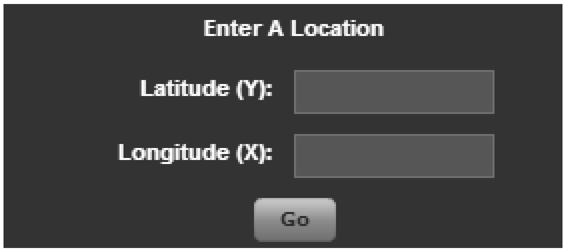

Figure 28: Entering a Location in the PV Watt Application.

As shown in Figure 29, a new window will then appear for entering system specifications and electricity costs.

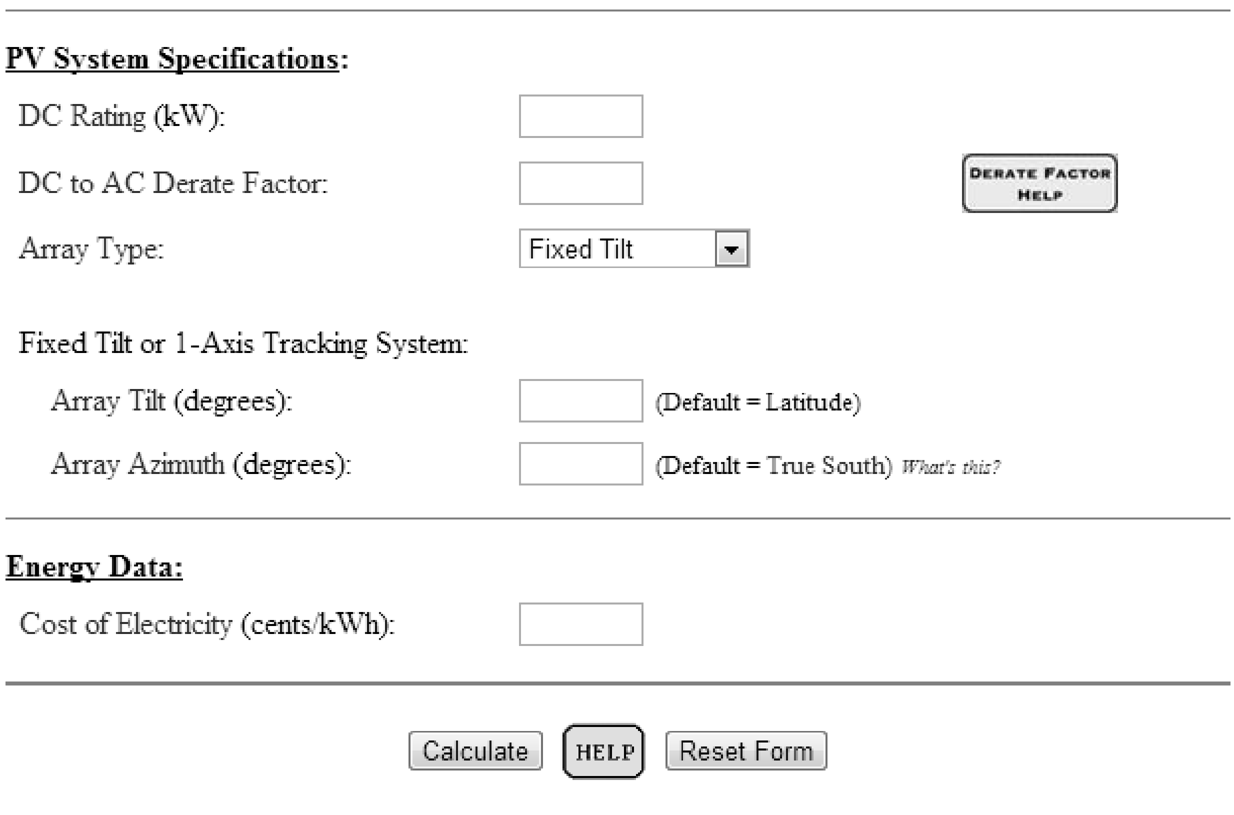

Figure 29: Entering PV System Specifications and Electricity Costs.

The DC rating was entered according to the values that were collected via online quotes and US Department of Energy recommendations regarding the size of a standard PV system. The

DC to AC derate factor is a parameter, which is used by the PV Watt calculator to indicate the efficiency of a PV system. Table 11 lists the parameters of the derate factors were used by the PV Watt calculator.

Table 11

Derate Factors for AC Power Rating

Component Derate Factors	PVWatts Default
PV module nameplate DC rating	0.95
Inverter and transformer	0.92
Mismatch	0.98
Diodes and connections	0.995
DC wiring	0.98
AC wiring	0.99
Soiling	0.95
System availability	0.98
Shading	1.00
Age	1.00
Overall DC-to-AC derate factor	0.77

Based on analysis of the data entered, the application will show the cost of electricity for a particular area in terms of rate per kilowatt hour. If the area is not covered by any utility provider, it will show the rate for the nearest utility service area.

There are three array types: fixed tilt, one-axis tracking, and two-axis tracking. For a fixed PV array, the tilt angle is the angle from horizontal of the inclination of the PV array (0° = horizontal, 90° = vertical). For a sun-tracking PV array with one axis of rotation, the tilt angle is the angle from horizontal of the inclination of the tracker axis. The tilt angle is not applicable for sun-tracking PV arrays with two axes of rotation. According to the U.S Department of Energy, the default value is a tilt angle equal to the station's latitude. Use of this normally maximizes annual energy production. Increasing the tilt angle favors energy production in the winter, and decreasing the tilt angle favors energy production in the summer.

After entering all the parameters and clicking “calculate,” a new window will appear that will contain data regarding the system specifications, electricity cost, and expected energy production of a standard PV system. Figure 30 shows an example of the results obtained regarding PV system performance for one of the cities in the State of Indiana that were generated using the default values of the parameters.

Station Identification	
Cell ID:	0242368
State:	Indiana
Latitude:	41.5 ° N
Longitude:	87.4 ° W
PV System Specifications	
DC Rating:	4.00 kW
DC to AC Derate Factor:	0.770
AC Rating:	3.08 kW
Array Type:	Fixed Tilt
Array Tilt:	41.5 °
Array Azimuth:	180.0 °
Energy Specifications	
Cost of Electricity:	11.6 ¢/kWh

Results			
Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)	Energy Value ($)
1	3.01	300	34.79
2	3.83	339	39.32
3	4.36	415	48.13
4	5.14	455	52.77
5	5.45	477	55.32
6	5.51	457	53.00
7	5.44	456	52.89
8	5.14	435	50.45
9	4.91	410	47.55
10	4.12	374	43.38
11	2.60	236	27.37
12	2.52	243	28.18
Year	4.34	4598	533.28

Figure 30*:* Sample of the Results Using the Default Values of the Parameters.

Once the technical requirements of the standard PV system have been stated, the economic analysis, which was the final step in the research methodology, carried out. The economic assessment included both costs and benefits of the system. The methodology for this assessment constituted a major portion of this study. The economic assessment was conducted by using Excel spreadsheets for calculation of the financial parameters, including cash flows, project balance (PB), net present value (NPV), and internal rate of return (IRR). Figure 31 shows the process that was used to make the economic assessment for the standard PV system.

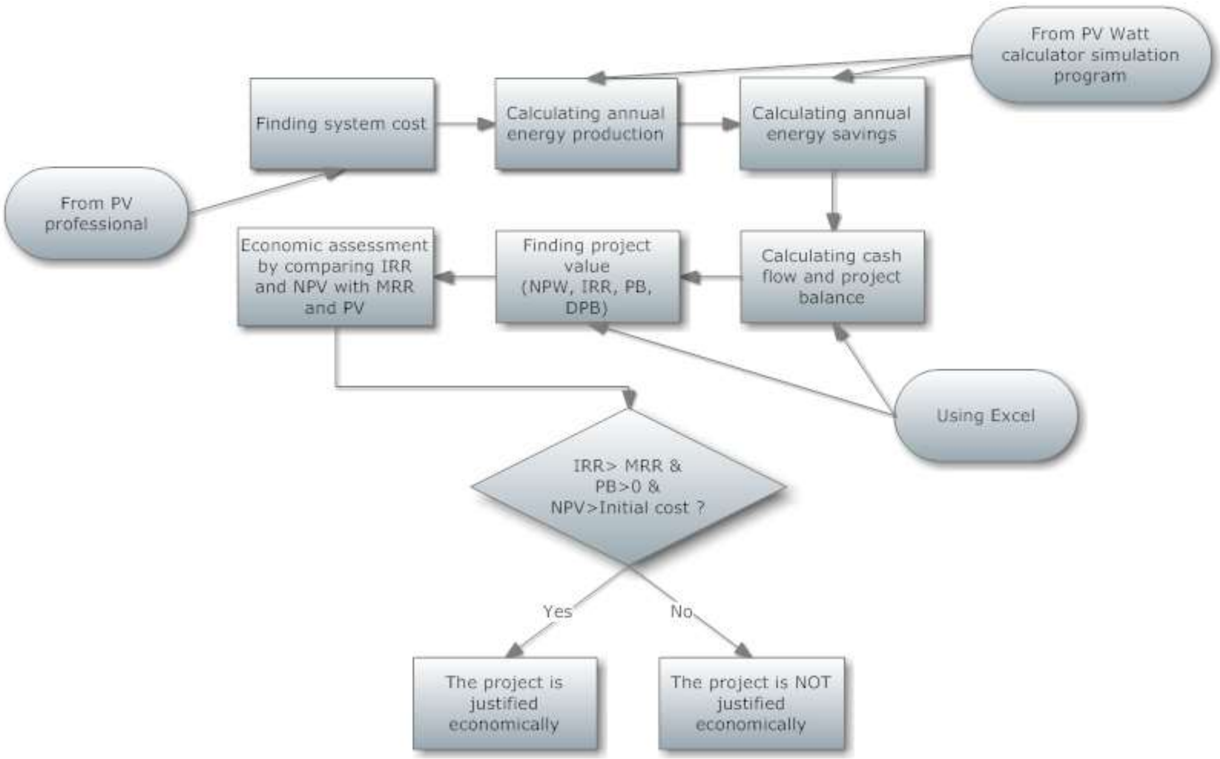

Figure 31: The Process of Making the Economic Assessment for the Standard PV System

The PB starts with negative values in this case as it is an investment project in a PV system. The project balance (PB) for the year 0 is equal to the cash flow for year 0, and it is equal to initial cost and the installation costs. For the remaining years, PB can be calculated by multiplying the project balance of the previous year (*t*-1) by the interest rate (*i*) and adding cash flow of that year (*t*).

$PB_t = [PB_{t-1} * (1+i)] + CF_t$……………………………… Equation 3 (repeated from chapter 2)

If PB reaches ‘zero’ at a particular time while changing from negative to positive values, this time is referred to as DPP. If PB remains negative till the end of the analysis period (e.g., n = 25 years) meaning the project is not justified economically.

Project balance (PB) helps to determine the discounted payback period (DPP). PB vs time (year) can be plotted to determine the discounted payback period (DPP). The DPP over 25 years has been calculated along with the internal rate of return (IRR) and the net present value (NPV) or present worth (PW). IRR is the interest rate (i*) at which the project benefits are equivalent to the project costs or the present worth (PW) of the project is zero. IRR (i.e., i*) can be obtained by solving Equation 4 for i*:

$$PW(i^*)=0= PW(i^*)_{\text{benefit}} - PW(i^*)_{\text{cost}} = \sum_{t=0}^{n} CF_t (1+i^*)^{-t}$$ … Equation 4 (repeated from chapter 2)

NPV or net PW or PW represents an equivalent amount of the project cash flows at t = 0 (i.e., present time) at interest rate (i). PW (i) can be obtained using Equation 6 (Newnan, Eschenbach, & Lavelle, 2011):

$$NPV(i)=PW(i)= PW(i)_{\text{benefit}} - PW(i)_{\text{cost}} = \sum_{t=0}^{n} CF_t (1+i)^{-t}$$ … Equation 6 (repeated from Ch 2)

NPV can also be computed from a range of cash flows (from period 1 to *n*) using the NPV function in the Microsoft Excel as given below (Newnan, Eschenbach, & Lavelle, 2011). If NPV is less than present value of the system, the project is concluded to be not justified.

NPV:=NPV(rate, values) …………………………… Equation 7 (repeated from chapter 2)

IRR can also be computed from a range of cash flows (from period 0 to n) using the IRR function in the Microsoft Excel as given below (Newnan, Eschenbach, & Lavelle, 2011). If IRR is less than market interest rate or MARR (refer to the definition in chapter 1), the project is concluded to be not justified.

IRR:=IRR(values, [guess]) ……………………………….Equation 5 (repeated from chapter 2)

Thus, DPP, values of PB at n = 25 and NPV and IRR for n = 25 can be used to evaluate the economic feasibility of installing a grid-connected PV. The total system's cost (which was collected from PV professionals) and the projected cash flows (which were based on analysis of system costs, expected energy production, electricity rate, maintenance expenses, expected lifetime, and interest rate) were the two most important factors for conducting this analysis. The following chapter explains the means of engineering analysis of the parameters were used in this study to determine the viability of standard PV system in greater detail.

Figure 32 summarizes the methodology of this research. Figure 33 shows a similar methodology, which is used by Whisnant, Johnston, and Hutchby (2003).

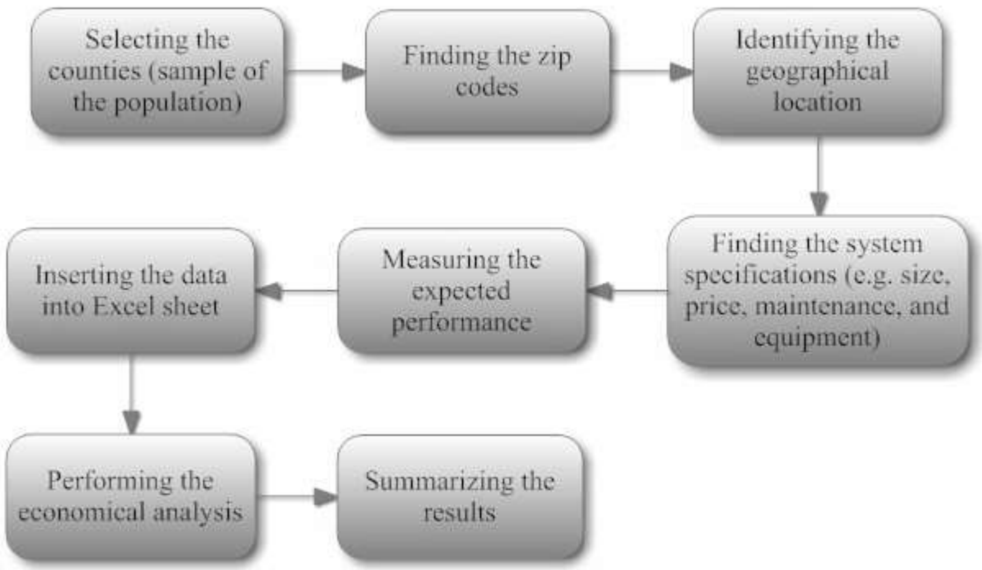

Figure 32: Research Methodology

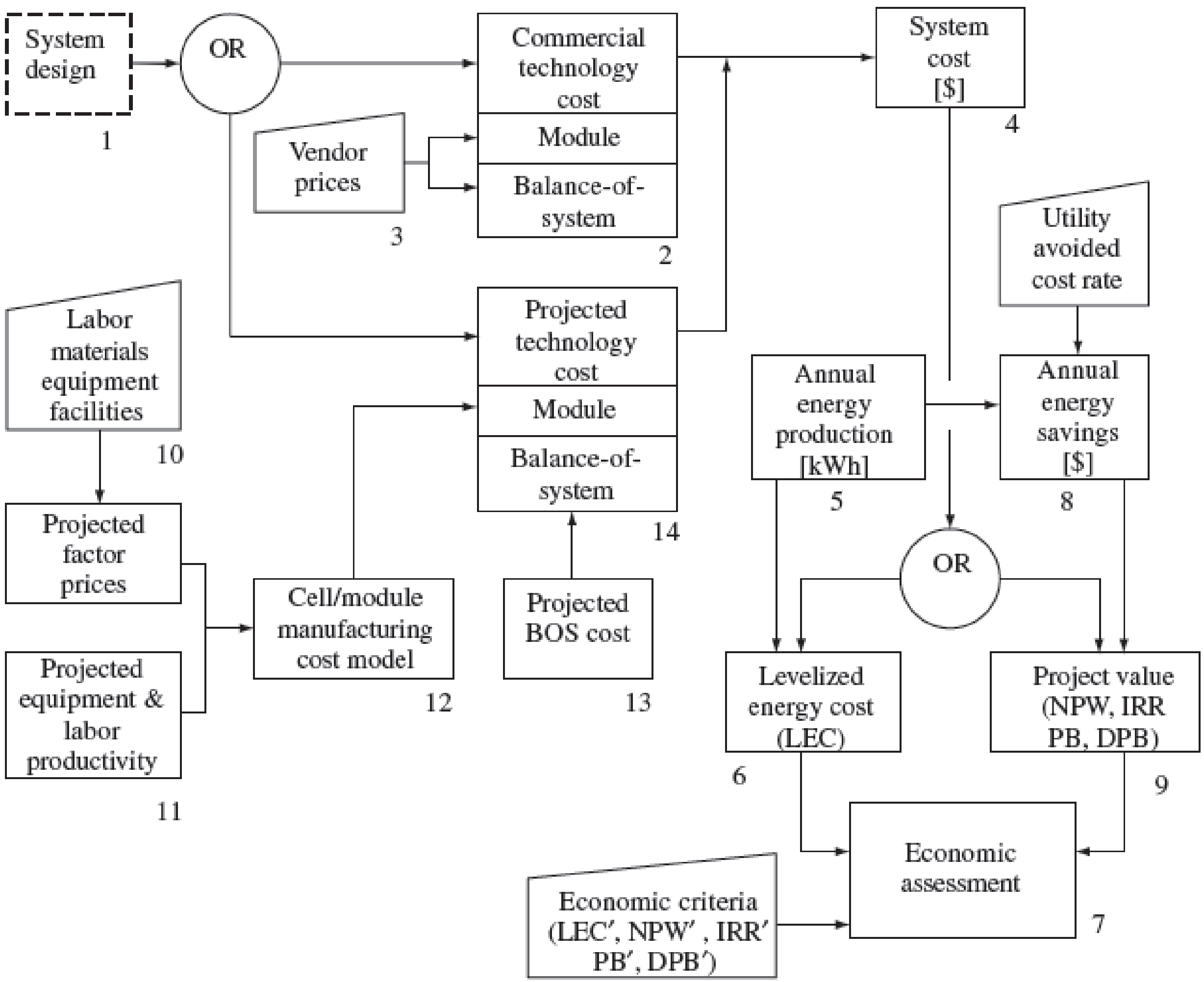

Figure 33: Economic assessment for a PV system (Whisnant, Johnston, & Hutchby, 2003).

Summary

This study has employed a systematic approach to collect data via reviewing the relevant literature, requesting information from PV professionals, and accessing the State of Indiana. A computer simulation program called PV Watt Calculator was used to estimate a standard system’s performance. Particular care was taken when collecting and analyzing data during the course of this dissertation to maximize the validity and reliability of the study. The results of the analysis were used to answer the study questions and presented in the form of graphics.

CHAPTER 4

FINDINGS

Chapter Three describes the methods and the tools were used in the study. This chapter presents the data that have been gathered using different tools including: the PV Watt application, the Websites of the U.S. Department of Energy and the State of Indiana, and online quotes. It also describes the techniques were used in the analysis of the data collected. A description of the findings relevant to the problem and hypothesis are explained. First, data about system cost, component, size, maintenance, and lifetime is presented. Next, the process of performing the feasibility analysis is explained and the results of the analysis were used to answer the research questions. In addition, charts are provided to represent the results. Finally, there appears a summary of the research results.

Overview

Using the tools and equipment described in Chapter Three, the study was built and the appropriate data were collected. Again, the statement of the problem is as follows: The lack of knowledge regarding the economic assessment of installing and using a residential grid-connected PV system has resulted in a low number of homeowners installing the systems in the state. Therefore, this study aims to measure the financial needs and viability of installing and using a residential grid-connected PV system in the State of Indiana while predicting its performance in different geographical locations (eighteen locations) within the state over the system's expected lifetime. The null hypothesis of the study is that installing a PV system for a single family residence in the State of Indiana will not pay for itself within 25 years; while the alternative hypothesis argues that it will reach the break-even point within 25 years assuming the average cost of a system. The research questions are:

19. What is the precise size of a PV system suitable for a typical single family home in Indiana?
20. How much does a standard PV system cost?
21. How much electricity will a standard PV system produce?
22. By how much will a standard PV system reduce electricity expenses?
23. Is a standard PV system, without government subsidy support, financially attractive investments to Indiana homeowners?
24. Does the Federal tax credit make it a good investment?
25. What is the payback period for a standard PV system?
26. What is the internal rate of return for a standard PV system?
27. How will future electric rate increases impact financial metrics, specifically internal rate of return?

Analytic Techniques

Given the type of data that were available, the analytic technique chosen for use in this study is an engineering economic analysis. The analysis includes measuring the following: internal rate of return, net present value, cash flow, and breakeven points. These calculations were done by analyzing important parameters: the average net cost of the typical PV system, the life of service, the amount of the expected energy produced, the market interest rate, and the electricity rate.

Description of Findings

This section describes the research findings details including: system and cost specification, system efficiency, and the economic analysis in each Indiana location studied.

The System Specification

PV professionals in the State of Indiana estimated a standard size of a PV system suitable for an average single family home in Indiana, to be 9.36 KW. The system consists of 36 panels of 260 W each and enables a household to generate 11,000 kWh per year. The system is enough to supply a typical house in Indiana with the needs of electricity (refer to chapter 2 for more detail about typical house appliances). Installing this system could eliminate the need for buying electricity by up to 100% because it generates all the electricity needed for a single household in the State of Indiana, and excess electricity could be sold back to the electric utility to offset power needed at night.

Table 12

System Specifications

PV System Specifications	
DC Rating:	9.36 kW
DC to AC Derate Factor:	0.77
AC Rating:	7.21 kW
Array Tilt:	32.0°
Array Azimuth:	180.0°
Array Type:	Fixed Tilt
Weight per Panel:	46.7 lbs
Panel Width:	39.41
Panel Length:	65.94
Total Panels:	36

The cost specification

The cost of a standard PV system varies from one manufacturer to another and depends on the system's configuration (e.g., roof or ground mounted, accessories…). The data regarding the system component and the rates have been collected via the process of requesting online quotes. Quotes were obtained from 13 of the 23 providers with online quotes capability. The rates for the system components are summarized in Table 13.

Table 13

The Rates for the Solar System Parts

Provider	Solar panels Price ($ per W)	Inverter	Racking, Mounting, Wires, and accessories
1	$1.59	$2,543.21	$140.72
2	$1.89	$2,646.15	$55.12
3	$2.13	$2,785.19	$57.23
4	$2.43	$2,841.03	$64.46
5	$2.28	$2,895.00	$75.55
6	$2.53	$2,842.53	$65.61
7	$2.63	$2,449.77	$76.73
8	$2.80	$2,510.45	$87.83
9	$2.75	$2,527.69	$90.91
10	$3.13	$2,357.90	$99.03
11	$3.43	$2,391.50	$100.09
12	$3.89	$1,789.50	$91.10
13	$4.45	$3,089.50	$124.14
Average	$2.76	$2589.96	$86.81
Total	$25869.60 (for 9.36 KW)	$2,589.96	$781.28 (for 9 racks)
Total Cost		$ 29,240.84	

The cost of the PV panels ranges from $1.59 to $4.45 per Watt. The average cost for installing a 9.36 kW system is $ 2.76 per Watt. From the online quotes, the researcher found that the PV manufacturers in the State of Indiana provide a warranty of 25 years for the panels and 10 years for the inverter. The price of the inverter ranges from $ 1,789.5 to $ 3,089.5. The average price for an inverter is $ 2,589.96. The maximum cost for a standard PV system is $44,882.22 (4.45*9360+3089.5+140.72). The minimum cost is $16,727.02 (1.59*9360+1789.5+55.12). The average cost for a standard PV system is $ 29,240.84 ($25,869.60 +$2,589.96 +$781.28). The average price was used in this study to calculate expected cash flows of the system. The system price includes 36 panels to generate kWh per year, one inverter, nine rack systems, accessories (e.g., wires, connectors, breakers, and switches…), and installation. There is no maintenance required for the system but it is suggested that a household buy a new inverter every 10 years.

Homeowners in the State of Indiana are eligible to receive a 30 percent federal tax credit for the installation of solar technologies. The federal tax credit is Residential Renewable Energy Tax Credit and if a taxpayer owes less than the tax credit, the excess credit generally may be carried forward to next tax year. This tax credit reduced the average net cost for a standard system to $20,468.588 ($ 29,240.84 – $8,772.252). Other parameters that should be considered in the analysis process are the market interest rate 3% (according to Indiana Department of Revenue), production degradation is equal to 3% per year starting from the second year (Energy Efficiency & Renewable Energy, 2008; El–Bassiouny & Mohamed, 2012; Jha, 2010) and the yearly increase in the cost of electricity 1.052 % (refer to chapter 2 for more details about this percentage).

The system efficiency

The amount of the expected energy produced depends on the geographical location of each city in the State of Indiana. This location can be identified by zip code, which identifies two factors: solar azimuth and solar altitude. Also, electricity rates vary from one location to another. The PV Watt application will show the cost of electricity for a particular area in terms of rate per kilowatt hour. If the area is not covered by any utility provider, it will show the rate for the nearest utility service area. The expected energy produced and the electricity rate was identified by the PV Watt application. The efficiency of the system is called the DC to AC derate factor.

Table 11 lists the parameters of the derate factors that are used by the PV Watt calculator and their ranges. According to the U.S. Department of Energy, the efficiency of the system (derate factor) is considered to be 77%. In order to consider degradation factor, the system performance (electricity production) is reduced by 3% per year starting from the second year.

The system economic analysis

The analysis depends on the following parameters:

1- The average net cost of a standard system = total cost - federal taxes credit (30% of the total cost).

   The average net cost of a standard system = \$ 29,240.84 – (\$ 29,240.84* 30%)

   = \$ 29,240.84 – \$8,772.252

   = \$20,468.588

2- Geographical location of an area (depends on solar azimuth and solar altitude).

3- Electricity cost (varies from area to other).

4- Sales Tax= 7%.

5- The market interest according to Indiana Department of Revenue rate =3%.

6- The yearly increase in rates of electricity =1.052% (refer to chapter 2 for more details about this percentage).

7- Degradation factor = 3% starting from the second year (U.S. Department of Energy, 2012).

8- Yearly Maintenance = 0.

9- Salvage value = Decommissioning cost.

10- Array Tilt =32° (U.S. Department of Energy, 2012).

11- Array Azimuth =180° (U.S. Department of Energy, 2012).

12- Panels lifetime =25 years (According to the PV professionals in Indiana).

13- Inverter lifetime = 10 years (According to the PV professionals in Indiana).

The specifications mentioned above were used to economically evaluate the viability of the system. The calculation of the annual cost or savings from the PV system depends on how much electricity was generated per month or per year. Electricity generated from the system was computed based on the available solar potential of the counties of Indiana. Total monthly and yearly generation of electricity from the system was calculated and has been presented.

The interest rate is equal to 3%, which calculated according to Indiana Department of Revenue. The electricity rates were computed according to the rates that are provided by the utility company that serves the area. The electricity cost is considered to increase 1.052% every year. Savings were computed by multiplying the electricity cost with the amount of electricity generated. Again, it has been considered that the system efficiency is 77%, which is the derate factor. Starting from the second year, degradation factor was considered to be equal to 3% per year. Cash flows and project balances for a standard system over an analysis period of 25 years are presented for each of the selected counties (regions of the state).

The cash flow at the end of the first year is the saving due to electricity generation multiplied by the state sales tax of 7%. The cash flows for the remaining years have been computed by multiplying the cash flow for the previous year by 1.052 (to account for the 1.052% yearly increase in electricity cost) and by 0.97 (to account for a 3 % yearly decrease in system efficiency or to count degradation factor). A household is advised to replace the inverter every 10 years. Therefore, assuming the inverter average cost remains the same during the system lifetime; $2,589.96 was added to the project balance at the 10th and 20st year. An analysis period for this work has been calculated to be 25 years because the warranty for the system is 25 years. Project balance amounts were calculated using Equation (3):

$PB_t = [PB_{t-1} * (1+i)] + CF_t$………………………………. Equation 3 (repeated from chapter 2)

where PB_t is the project balance for the current year t; PB_{t-1} is the previous year project balance; and CF_t is the current year cash flow.

Project balance helps to determine the discounted payback period (DPP), which is defined as the number of periods until the compounded sum of net revenues equals the compounded value of the initial cost (Newnan et al., 2011). The DPP over 25 years has been calculated along with the internal rate of return (IRR) and the net present value (NPV). IRR is the interest rate (i*) at which the project benefits are equivalent to the project costs or the present worth (PW) of the project is zero. IRR (i.e., i^*) can be obtained by solving Equation 4 for i^*:

$PW(i^*)=0= PW(i^*)_{\text{benefit}} - PW(i^*)_{\text{cost}} = \sum_{t=0}^{n} CF_t (1+i^*)^{-t}$ ... Equation 4 (repeated from chapter 2)

IRR can also be computed from a range of cash flows (from period 0 to n) using the IRR function in the Microsoft Excel as given below (Newnan et al., 2011).

IRR:=IRR(values, [guess]) ……………………………..…Equation 5 (repeated from chapter 2)

NPV or net PW or PW represents an equivalent amount of the project cash flows at t = 0 (i.e., present time) at interest rate (i). NPV(i) can be obtained using Equation (6) (Newnan, Eschenbach, & Lavelle, 2011):

$NPV(i)=PW(i)= PW(i)_{\text{benefit}} - PW(i)_{\text{cost}} = \sum_{t=0}^{n} CF_t (1+i)^{-t}$ .. Equation 6 (repeated from chapter 2)

NPV can also be computed from a range of cash flows (from period 1 to n) using the NPV function in the Microsoft Excel as given below (Newnan, Eschenbach, & Lavelle, 2011).

NPV:=NPV(rate, values) ……………………………..…… Equation 7 (repeated from chapter 2)

If any cash flow occurs at $n = 0$, it is added algebraically to the value obtained from Equation 7 the excel NPV function.

Appendix C describes the monthly (and yearly) generation of electricity and the cash flows (and project balances) tables. The following sections provide the summary of the economic analysis for a standard system in each of the selected counties (regions of the state).

The economic analysis for the system efficiency in the selected counties

Lake County

Lake County was selected to represent the North region. There are 33 zip codes serving this county. There are two different latitudes and longitudes used for the county: the first location with latitude of 41.505 and longitude of -87.409; the second with latitude of 41.127 and longitude of -87.344. The cost of electricity in Lake County is 11.598 cents/kWh.

Lake County: Location #1

A standard system in the first location in Lake County generates 10864 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 34 shows the monthly energy generation in this area.

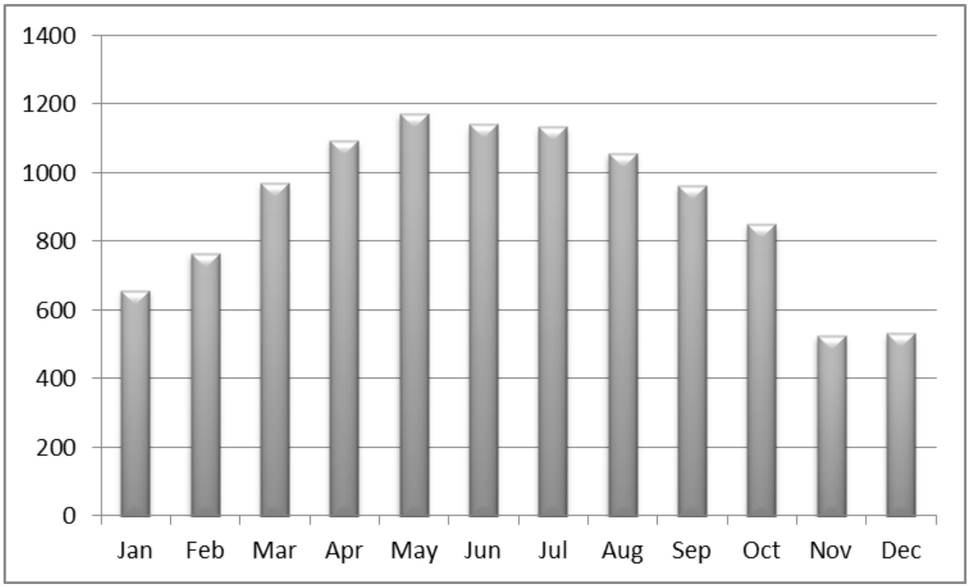

Figure 34: The Monthly Energy Generation in Lake County Location #1.

A household in this location could save $1,348.21 in the first year. The project at the end of year 25 has -$8,632.74 as a balance. Figure 35 shows the project balance during the 25 years. According to these numbers, the NPV is equal to $15,869.46, which is less than the initial cost for the system ($20,468.59), the IRR is 0.491%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 14 summarizes the results of the economic assessment. Appendix C includes more details about the cash flow, project balance, monthly energy generation, and solar radiations.

Table 14

The First Location in Lake County, Indiana

Station Identification	
Location:	1
County:	Lake County, Indiana
Latitude:	41.5 ° N
Longitude:	87.4 ° W
Cost of Electricity:	11.6 ¢/kWh
Generation Of Elect. kWh in the 1st Year	10864 kWh
Energy Value$/ per the first year	$1,348.21
PB	-$8,632.74
NPV	$15,869.46
IRR	0.491%

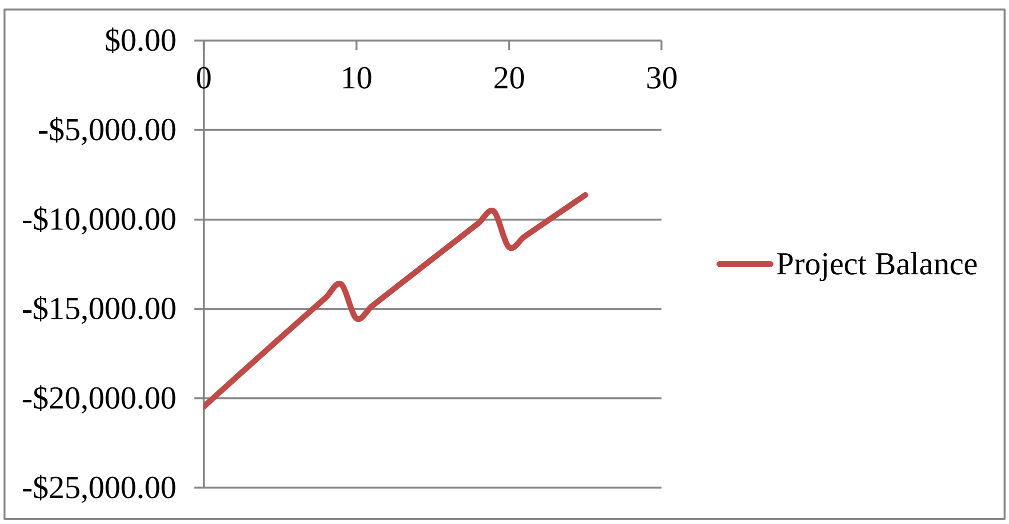

Figure 35: Project Balance for the System at First Location in Lake County

Lake County: Location #2

A standard system in the second location in Lake County generates 10935 kWh during the first year. After the first year, this amount is decreased by 3% / year due to degradation factor. Figure36 shows the monthly energy generation in this area.

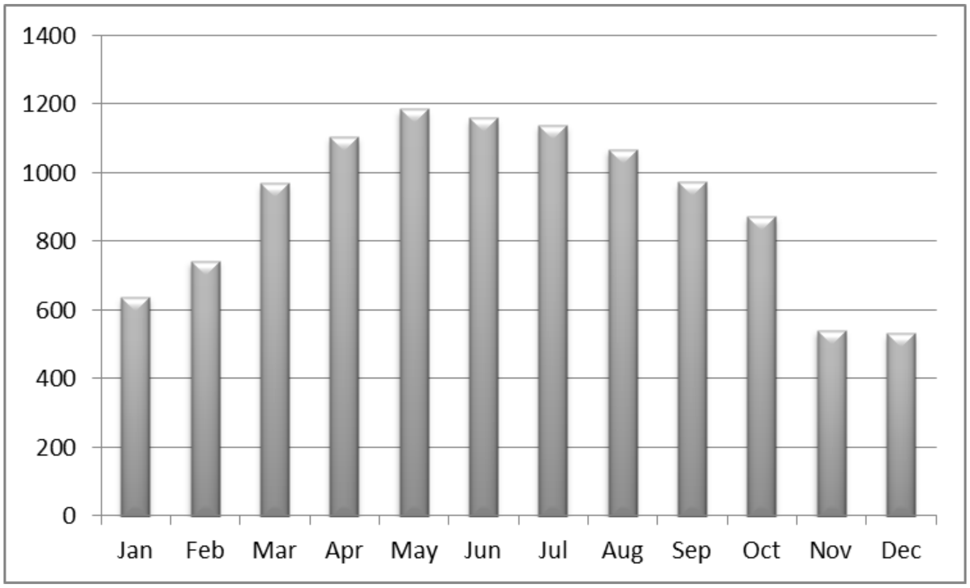

Figure 36: The Monthly Energy Generation in Lake County Location #2.

A household in this location could save $1,344.50 in the first year. The project at the end of year 25 has -$8,746.96 as a balance. Figure 37 shows the project balance during the 25 years. According to these numbers, the NPV is equal to $15,816.50, which is less than the present value for the system ($20,468.59), the IRR is 0.460%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in this area is not justified economically. Table 15 summarizes the results of the economic assessment. Appendix C includes more details about the cash flow, project balance, energy generation, and solar radiations.

Table 15

The Second Location in Lake County, Indiana

Station Identification	
Location:	2
County:	Lake County, Indiana
Latitude:	41.1 ° N
Longitude:	87.3 ° W
Generation Of Elect. kWh in the 1st Year	10935 kWh
Energy Value $/ year	$1,344.50
PB	-$8,746.96
NPV	$15,816.50
IRR	0.460%

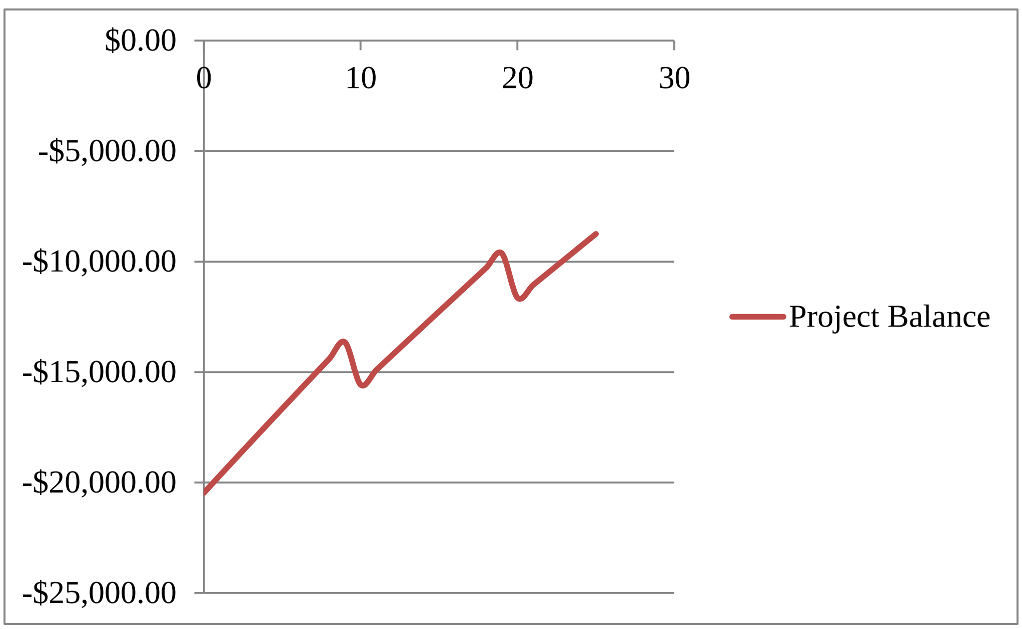

Figure 37: Project Balance for the System at the Second Location in Lack County

Allen County

Allen County was selected to represent the East region. There are 58 zip codes serving this County. There are five different latitudes and longitudes used for the county: the first location with latitude of 41.00° N, longitude of 85.20° W and the electricity rate in that area is 7.3 cents/kWh. The second location with latitude of 40.917, longitude of -85.285, and the electricity rate is 10.182 cents/kWh. The third location with latitude of 41.329, longitude of -84.827, and the electricity rate is 9.874. The fourth location with latitude of 40.95, longitude of -84.785, and the electricity rate is 9.7 cents/kWh. The last location with latitude of 41.295 and longitude of -85.332, and the electricity price is 9.964 cents/kWh.

Allen County: Location #1

A standard system in the first location in Allen County generates 10999 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 38 shows the monthly energy generation in this area.

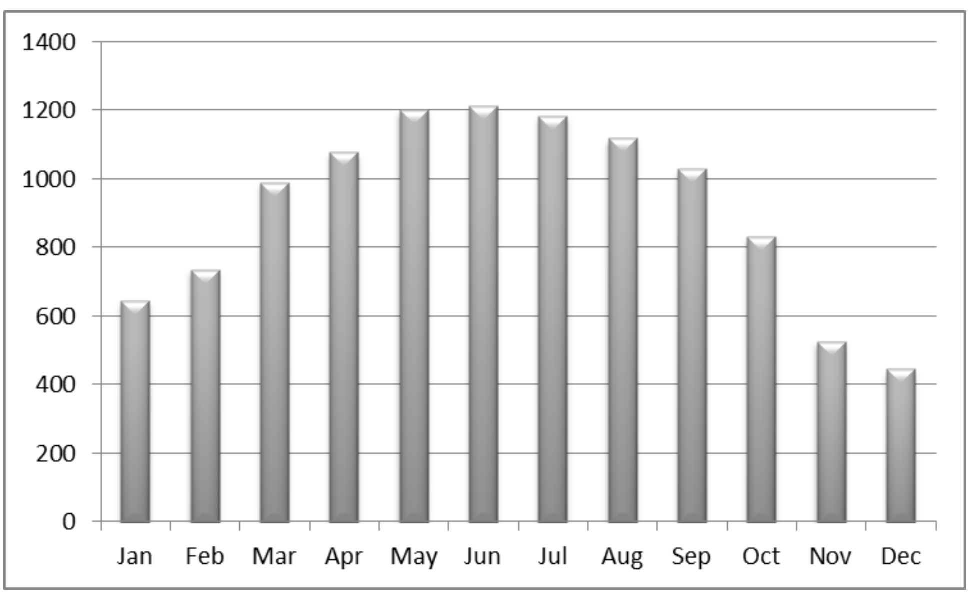

Figure 38: The Monthly Energy Generation in Allen County Location #1.

A household in this location could save \$859.14 in the first year. The project at the end of year 25 has -\$23,677.31as a balance. Figure 39 shows the project balance during the 25 years. According to these numbers, the NPV is equal to \$8,893.37, which is less than the present value for the system (\$20,468.59), the IRR is -4.427%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 16 summarizes the result of the economic analysis. Appendix C includes more details about the cash flow, energy generation, and solar radiations.

Table 16

The First Location in Allen County, Indiana

Station Identification	
Location:	1
County:	Allen County , Indiana
Latitude:	41.00° N
Longitude:	85.20° W
Generation Of Elect. kWh in the 1^{st} Year	10999 kWh
Energy Value \$/ 1^{st} year	\$859.14
PB	-\$23,677.31
NPV	\$8,893.37
IRR	-4.427%

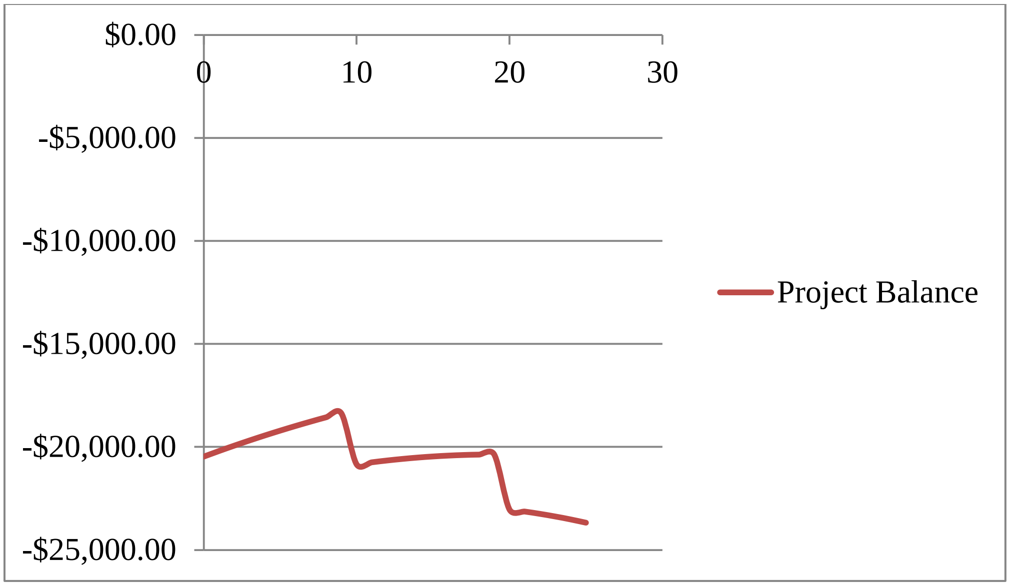

Figure 39: Project Balance for the System at the First Location in Allen County

Allen County: Location #2

The system in the second location in Allen County generates 10880 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 40 shows the monthly energy generation in this area.

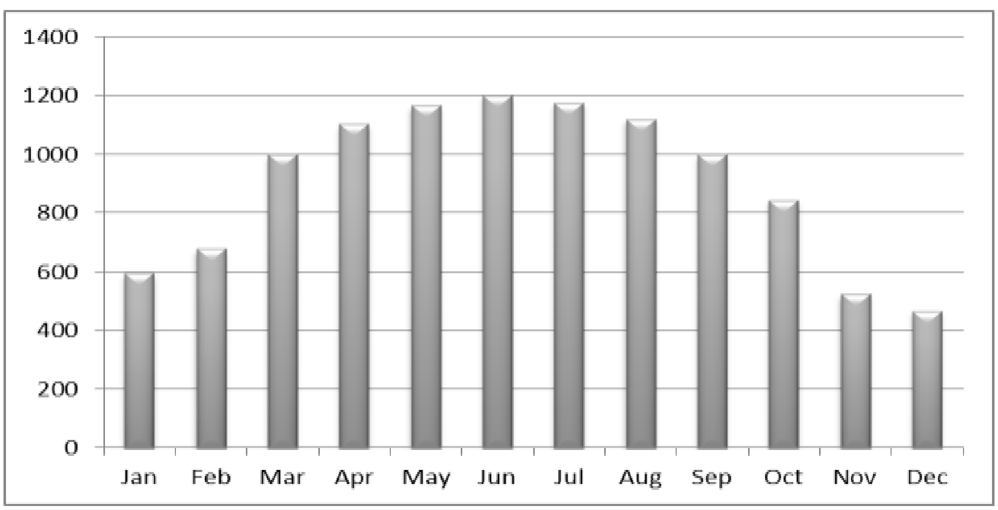

Figure 40: Monthly Generation of Electricity in Allen County, Location 2.

A household in this location could save $1,185.35 in the first year. The project at the end of year 25 has -$13,642.66 as a balance. Figure 41 shows the project balance during the 25 years. According to these numbers, the NPV is equal to $13,546.39, which is less than the present value for the system ($20,468.59), the IRR is -0.944%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 17 summarizes the result of the economic assessment. Appendix C includes more details about the cash flow, project balance, energy generation, and solar radiations.

Table 17

The Second Location in Allen County, Indiana

Station Identification	
Location:	2
County:	Allen County , Indiana
Latitude:	40.9 ° N
Longitude:	85.3 ° W
Generation Of Elec. kWh in 1st Year	10880 kWh
Energy Value $ in the 1st year	$1,185.35
PB	-$13,642.66
NPV	$13,546.39
IRR	-0.944%

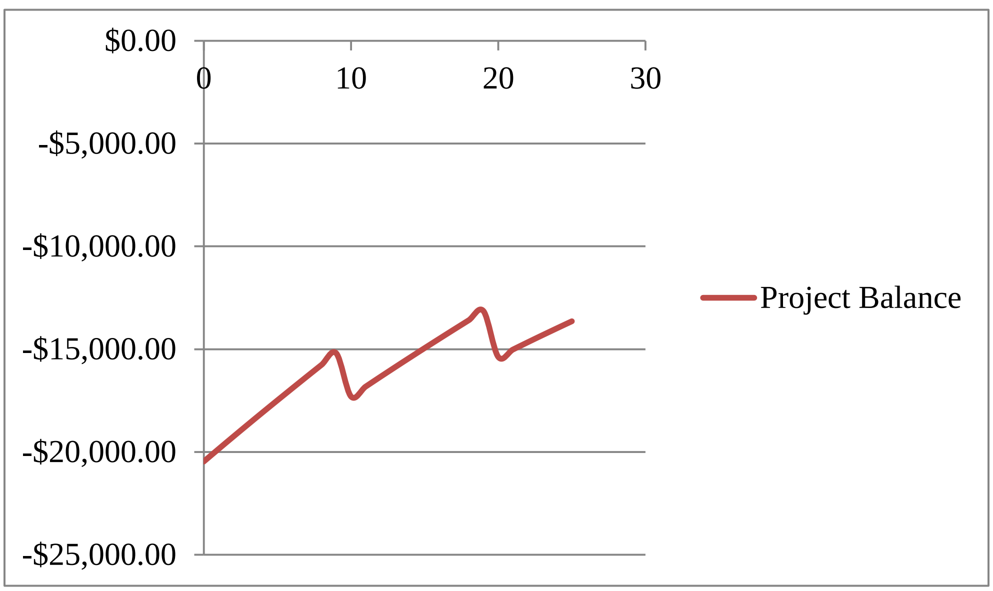

Figure 41: Project Balance for the System at the Second Location in Allen County

Allen County: Location #3

The system in the third location in Allen County generates 10842 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 42 shows the monthly generation of electricity in this area.

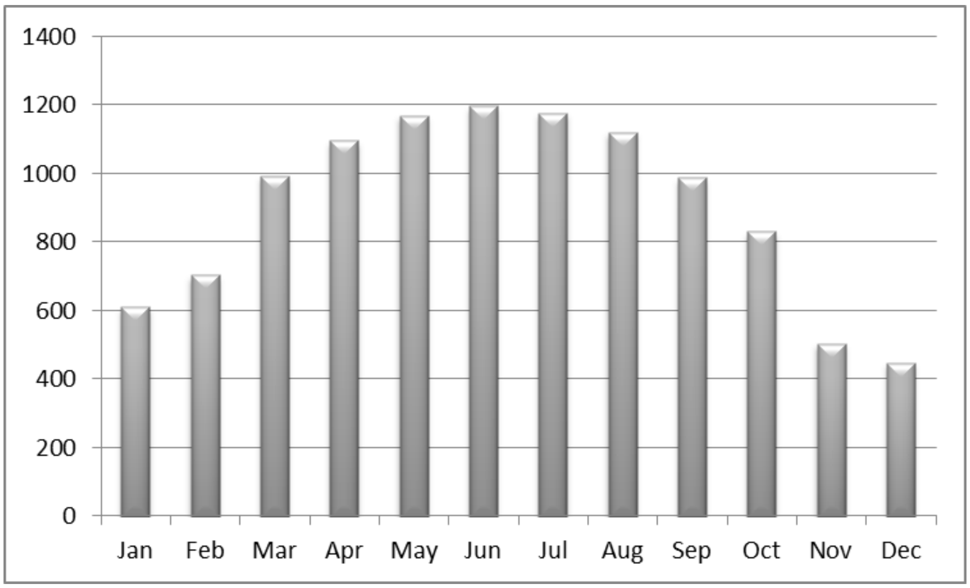

Figure 42: Monthly Generation of Electricity in Allen County, Location #3

A household in this location could save $1,145.48 in the first year. The project at the end of year 25 has -$14,869.06 as a balance. Figure 43 shows the project balance during the 25 years. According to these numbers, the NPV is equal to $12,977.71, which is less than the present value for the system ($20,468.59), the IRR is -1.319%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 18 summarizes the result of the economic assessment. Appendix C includes more details about the cash flow, energy generation, and solar radiations.

Table 18

The Third Location in Allen County, Indiana

Station Identification	
Location :	3
County:	Allen County, Indiana
Latitude:	41.3 ° N
Longitude:	84.8 ° W
Generation Of Elect. kWh in the 1st Year	10842 kWh
Energy Value $ in the 1st year	$1,145.48
PB	-$14,869.06
NPV	$12,977.71
IRR	-1.319%

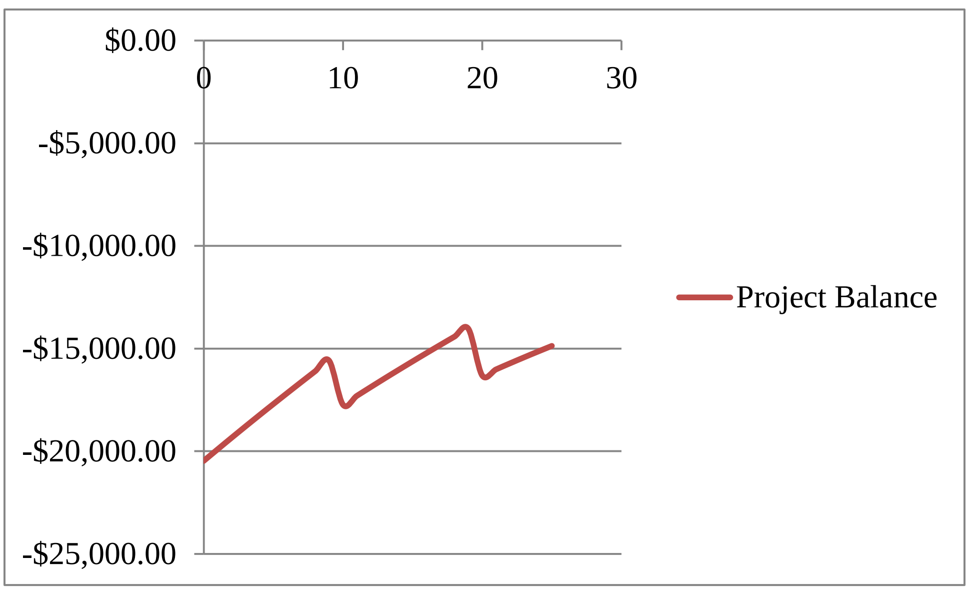

Figure 43: Project Balance for the System at the Third Location in Allen County

Allen County: Location #4

A standard system in the fourth location in Allen County generates 10890 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 44 shows the monthly generation of electricity in this area.

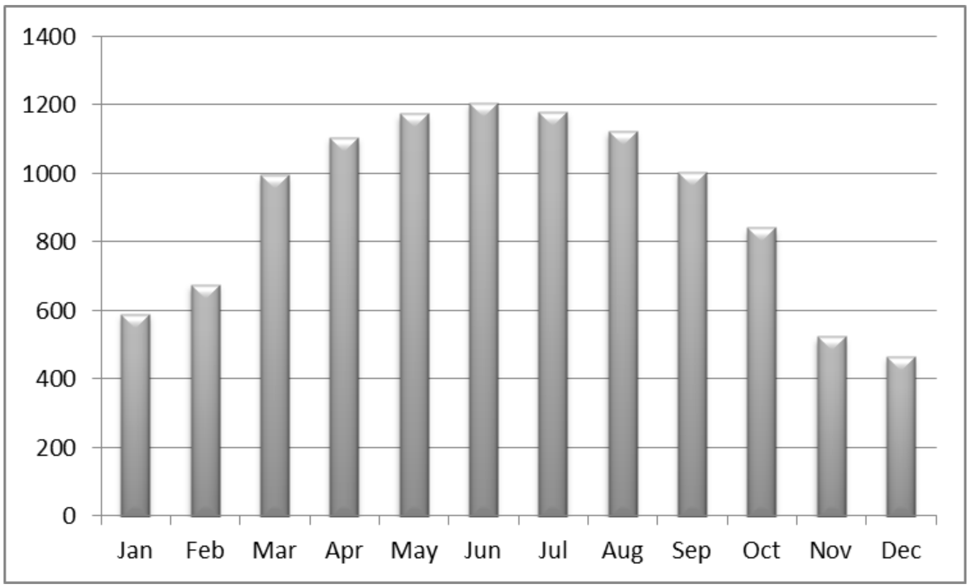

Figure 44: The Monthly Energy Generation in Allen County, Location #4

A household in this location could save $1,127.25 in the first year. The project at the end of year 25 has -$15,429.92 as a balance. Figure 45 shows the project balance during the 25 years. According to these numbers, the NPV is equal to $12,717.64, which is less than the present value for the system ($20,468.59), the IRR is -1.494%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 19 summarizes the result of the economic assessment. Appendix C includes more details about the cash flow, project balance, energy generation, and solar radiations.

Table 19

The Fourth Location in Allen County, Indiana

Station Identification	
Location :	4
County:	Allen County, Indiana
Latitude:	41.0 ° N
Longitude:	84.8 ° W
Generation Of Elect. kWh in the 1st Year	10890 kWh
Energy Value $ in the 1st year	$1,127.25
PB	-$15,429.92
NPV	$12,717.64
IRR	-1.494%

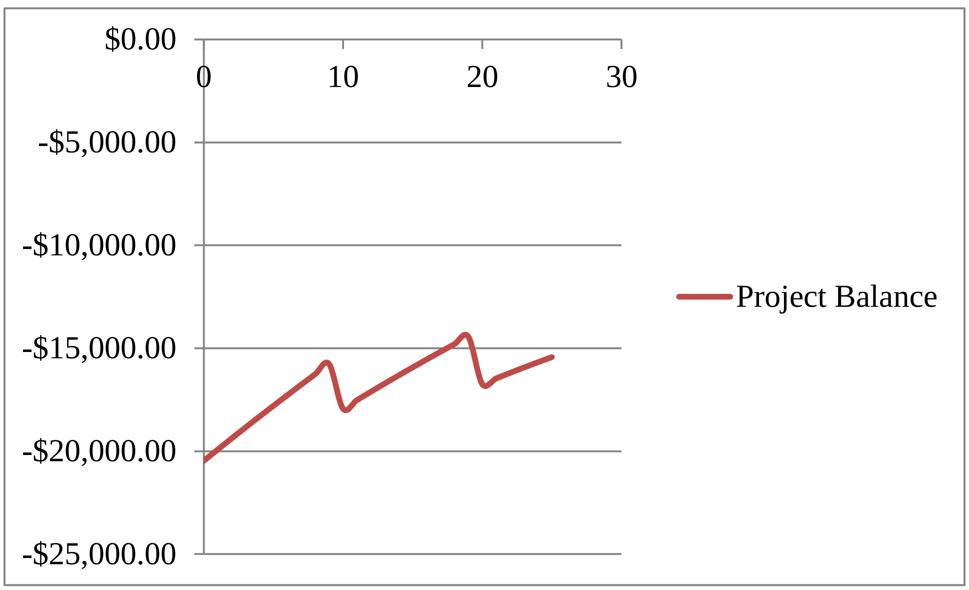

Figure 45: Project Balance for the System at the Fourth Location in Allen County

Allen County: Location #5

A standard system in the fifth location in Allen County generates 11472 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 46 shows the monthly generation of electricity in this area.

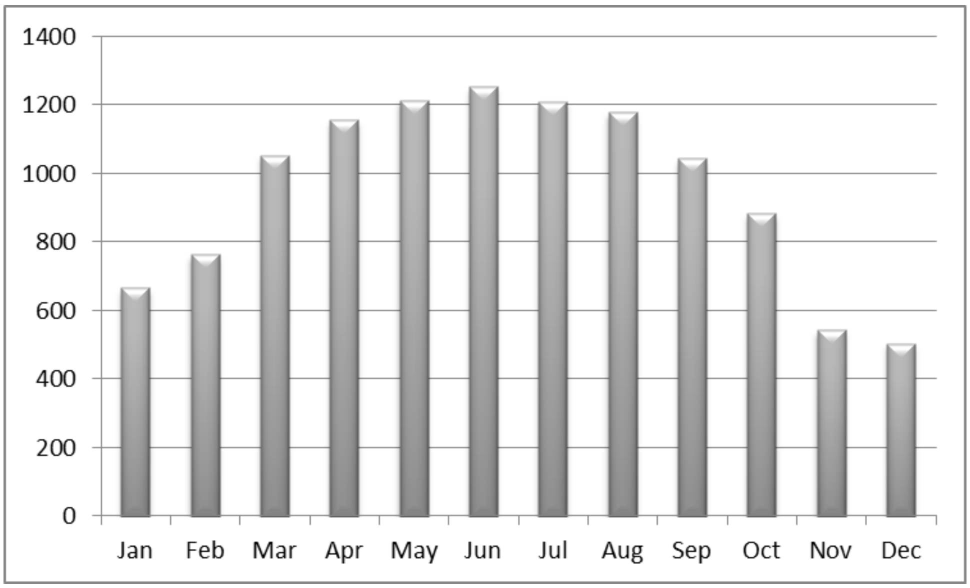

Figure 46: Monthly Generation of Electricity in Allen County, Location #5

A household in this location could save $1,223.08 in the first year. The project at the end of year 25 has -$12,481.77 as a balance. Figure 47 shows the project balance during the 25 years. According to these numbers, the NPV is equal to $14,084.69, which is less than the present value for the system ($20,468.59), the IRR is -0.598%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 20 summarizes the result of the economic assessment. Appendix C includes more details about the cash flow, project balance, energy generation, and solar radiations.

Table 20

The Fifth Location in Allen County, Indiana

Station Identification	
Location:	5
County:	Allen County, Indiana
Latitude:	41.3 ° N
Longitude:	85.3 ° W
Generation Of Elect. kWh in the 1st Year	11472 kWh
Energy Value $ in the 1st year	$1,223.08
PB	-$12,481.77
Energy Value $ in the 1st year	$1,223.08
NPV	$14,084.69
IRR	-0.598%

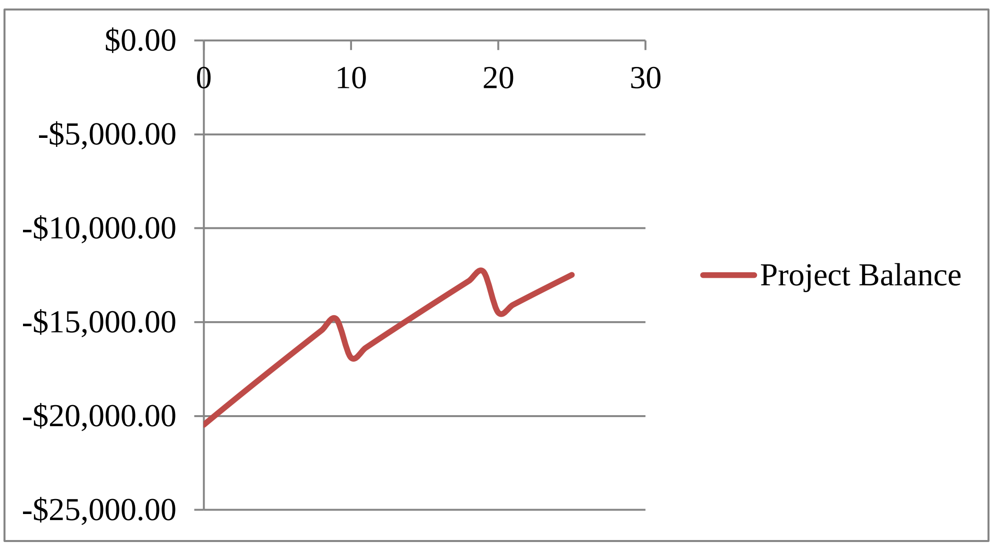

Figure 47: Project Balance for a Standard System at the Fifth Location in Allen County

Tippecanoe County

Tippecanoe County was selected to represent the West region. There are 21 zip codes serving this county. There are four different latitudes and longitudes used for the county: the first location with latitude of 40.421, longitude of -86.724, and the electricity cost is 10.954 cents/kWh. The second location with latitude of 40.045, longitude of is -86.667, and the electricity cost is 10.747 cents/kWh. The third location with latitude of 40.375, longitude of -87.217, and the electricity rate is 11.306 cents/kWh. Finally, the fourth with latitude of 40, longitude of -87.156, and the electricity rate is 10.917 cents/kWh.

Tippecanoe County: Location# 1

A standard system in the first location in Tippecanoe County generates 11043 kWh. Figure 48 shows the monthly generation of electricity in this area.

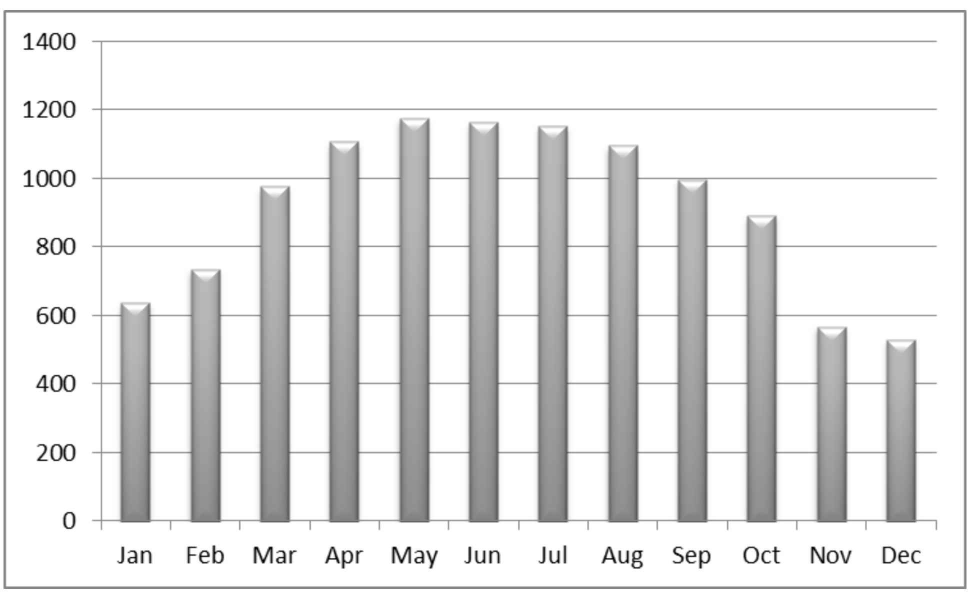

Figure 48: The Monthly Generation of Electricity in Tippecanoe County, Location# 1

A household in this location could save $1,294.33 in the first year. The project at the end of year 25 has -$10,290.32 as a balance. Figure 49 shows the project balance during the 25 years.

According to these numbers, the NPV is equal to \$15,100.85, which is less than the present value for the system (\$20,468.59), the IRR is 0.032%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 21 summarizes the result of the economic assessment. Appendix C includes more details about the cash flow, project balance, energy generation, and solar radiations.

Table 21

The First Location in Tippecanoe County, Indiana

Station Identification	
Location:	1
County:	Tippecanoe County , Indiana
Latitude:	40.4 ° N
Longitude:	86.7 ° W
Generation Of Elect. kWh in the 1st Year	11043 kWh
Energy Value \$ in the 1st year	\$1,294.33
PB	-\$10,290.32
NPV	\$15,100.85
IRR	0.032%

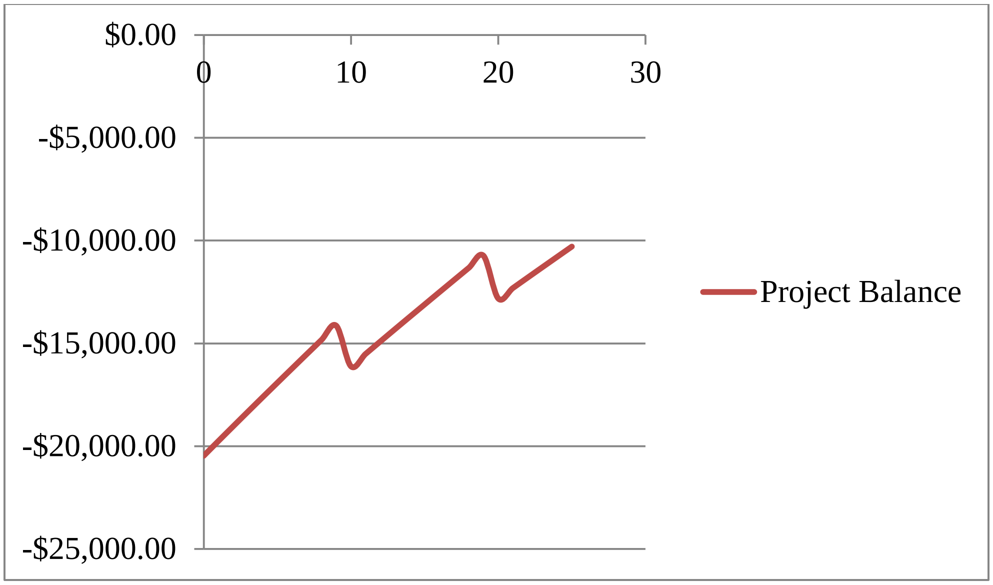

Figure 49: Project Balance for a Standard System at the First Location in Tippecanoe County

Tippecanoe County: Location# 2

A standard system in the second location in Tippecanoe County generates 11358 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 50 shows the monthly generation of electricity in this area.

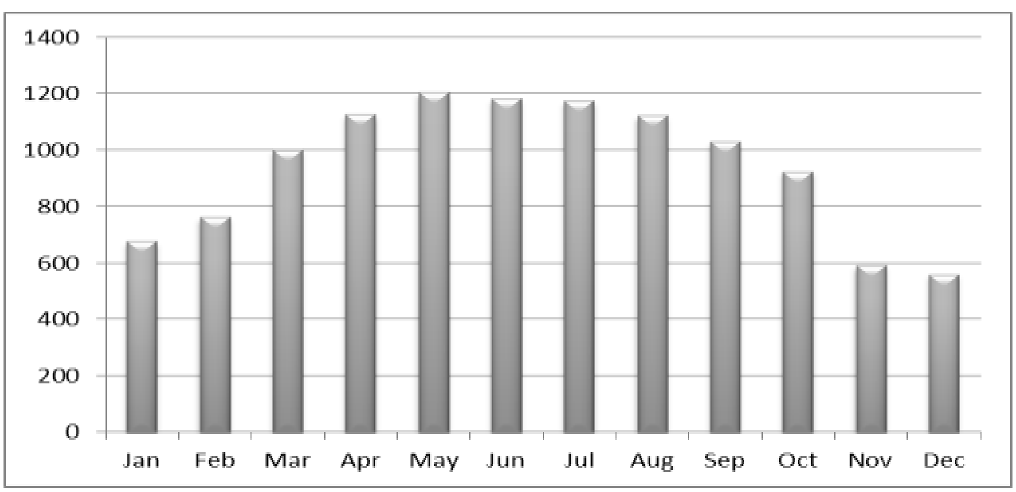

Figure 50: The Monthly Generation of Electricity in Tippecanoe County, Location# 2

A household in this location could save \$1,306.08 in the first year. The project at the end of year 25 has -\$9,928.59 as a balance. Figure 51 shows the project balance during the 25 years. According to these numbers, the NPV is equal to \$15,268.58, which is less than the present value for the system (\$20,468.59), the IRR is 0.133%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 22 summarizes the result of the economic assessment. Appendix C includes more details about the cash flow, project balance, energy generation, and solar radiations.

Table 22

The Second Location in Tippecanoe County, Indiana

Station Identification	
Location:	2
County:	Tippecanoe County , Indiana
Latitude:	40.0 ° N
Longitude:	86.7 ° W
Generation Of Elect. kWh in the 1st Year	11358 kWh
Energy Value \$ in the 1st year	\$1,306.08
PB	-\$9,928.59
NPV	\$15,268.58
IRR	0.133%

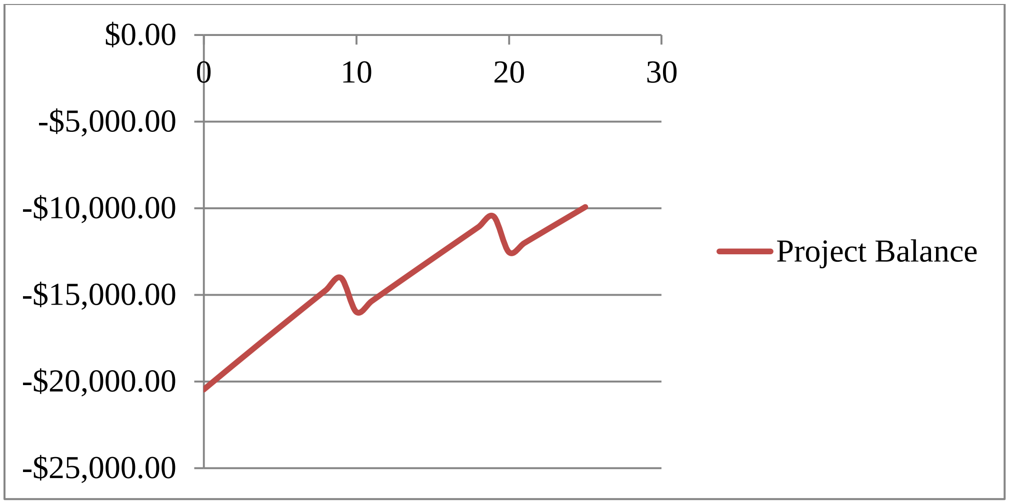

Figure 51: Project Balance for a Standard System at the Second Location in Tippecanoe County

Tippecanoe County: Location# 3

A standard system in the third location in Tippecanoe County generates 11277 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 52 shows the monthly generation of electricity in this area.

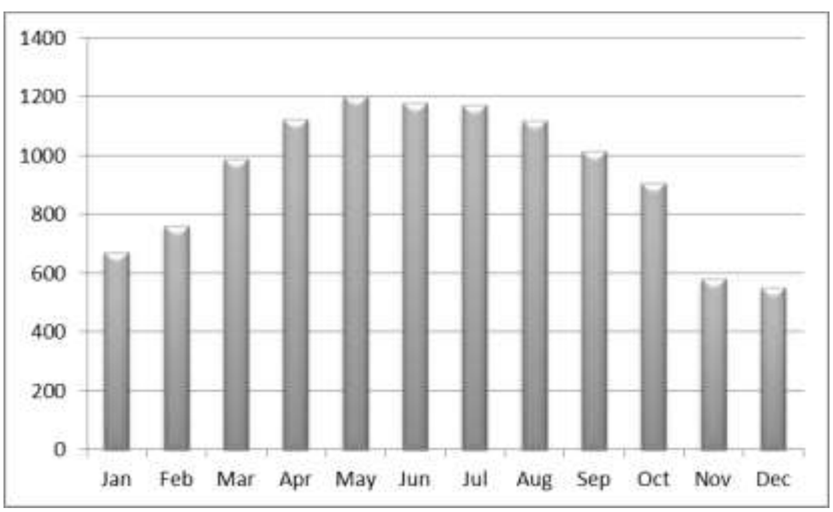

Figure 52: The Monthly Generation of Electricity in Tippecanoe County, Location# 3

A household in this location could save $1,364.23 in the first year. The project at the end of year 25 has -$8,140.01 as a balance. Figure 53 shows the project balance during the 25 years. According to these numbers, the NPV is equal to $16,097.93, which is less than the present value for the system ($20,468.59), the IRR is 0.625%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 23 summarizes the result of the economic assessment. Appendix C includes more details about the cash flow, project balance, energy generation, and solar radiations.

Table 23

The Third Location in Tippecanoe County, Indiana

Station Identification	
Location:	3
County:	Tippecanoe County, Indiana
Latitude:	40.4 ° N
Longitude:	87.2 ° W
Generation Of Elect. kWh in the 1st Year	11277 kWh
Energy Value $ in the 1st year	$1,364.23
PB	-$8,140.01
NPV	$16,097.93
IRR	0.625%

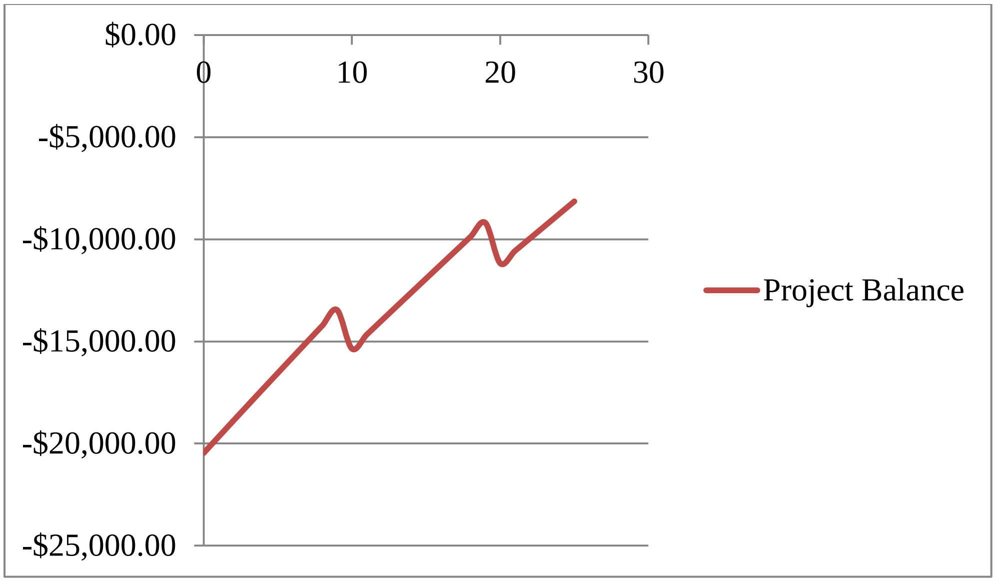

Figure 53: Project Balance for a Standard System at the Third Location in Tippecanoe County

Tippecanoe County: Location#4

A standard system in the fourth location in Tippecanoe County generates 11539 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 54 shows the monthly generation of electricity in this area

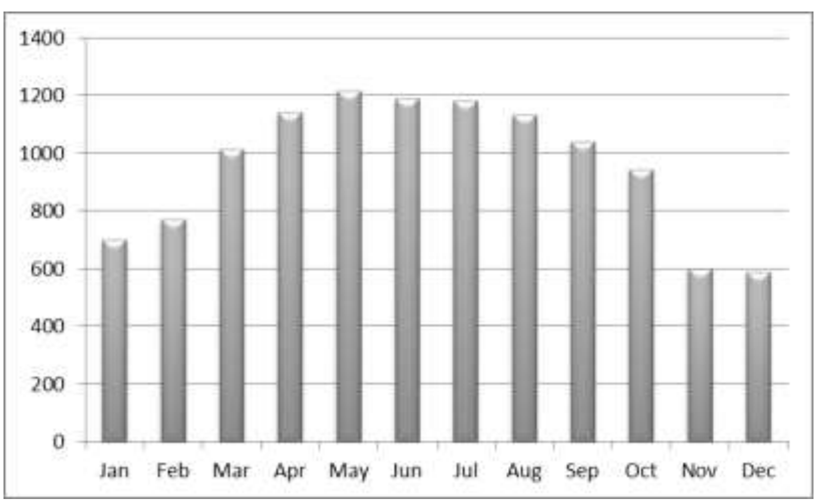

Figure 54: The Monthly Generation of Electricity in Tippecanoe County, Location# 4

The project at the end of year 25 has -\$8,642.62 as a balance. Figure 55 shows the project balance during the 25 years. According to these numbers, the NPV is equal to \$15,864.88, which is less than the present value for the system (\$20,468.59), the IRR is 0.488%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 24 summarizes the result of the economic assessment. Appendix C includes more details about the cash flow, project balance, energy generation, and solar radiations.

Table 24

The Fourth Location in Tippecanoe County, Indiana

Station Identification	
Location:	4
County:	Tippecanoe County, Indiana
Latitude:	40.0 ° N
Longitude:	87.2 ° W
Generation Of Elect. kWh in the 1st Year	11539 kWh
Energy Value \$ in the 1st year	\$1,347.89
PB	-\$8,642.62
NPV	\$15,864.88
IRR	0.488%

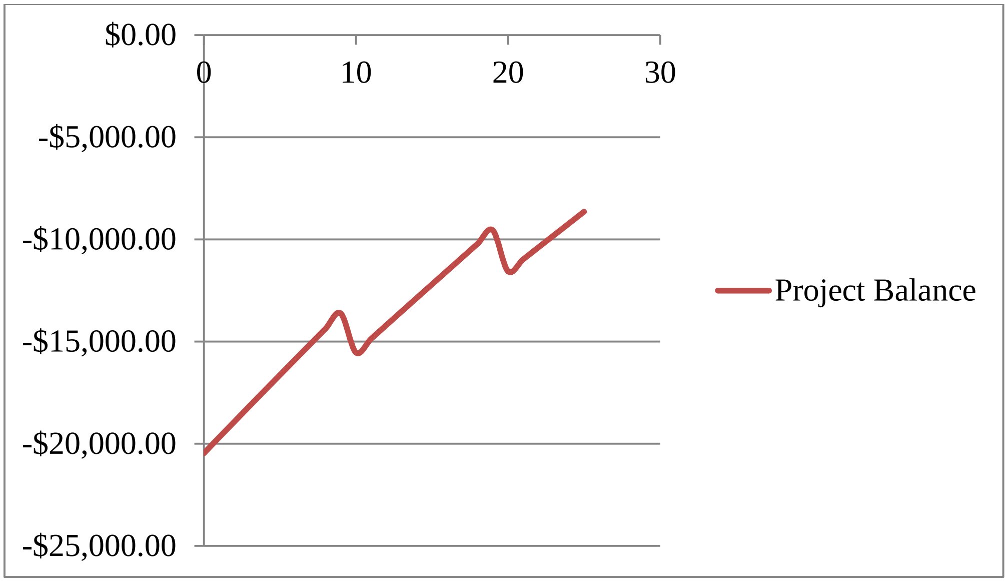

Figure 55: Project Balance for a Standard System at the Fourth Location in Tippecanoe County

Marion County

Marion County was selected to represent the Central region. There are 63 zip codes serving this county. There are two different latitudes and longitudes used for the county: the first location with latitude of 39.713, longitude of -86.124, and the electricity rate is 10.241 cents/kWh. The second location with latitude of 40.088, longitude of -86.177, and the electricity rate is 9.697cents/kWh.

Marion County: Location #1

A standard system in the first location in Marion County generates 11194 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 56 shows the monthly generation of electricity in this area.

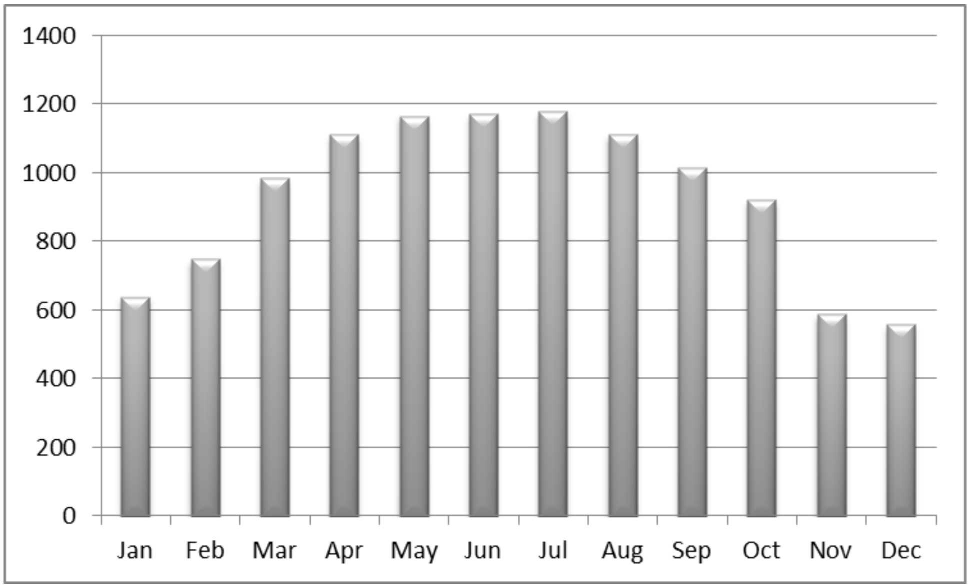

Figure 56: The Monthly Generation of Electricity in Marion County, Location #1

A household in this location could save $1,226.63 in the first year. The project at the end of year 25 has -$12,372.82 as a balance. Figure 57 shows the project balance during the 25 years. According to these numbers, the NPV is equal to $14,135.20, which is less than the present value for the system ($20,468.59), the IRR is -0.566%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 25 summarizes the result of the economic assessment. Appendix C includes more details about the cash flow, project balance, energy generation, and solar radiations.

Table 25

The First Location in Marion County, Indiana

Station Identification	
Location:	1
County:	Marion County , Indiana
Latitude:	39.7 ° N
Longitude:	86.1 ° W
Generation Of Electr. kWh in the 1st year	11194 kWh
Energy Value $/ year	$1,226.63
PB	-$12,372.82
NPV	$14,135.20
IRR	-0.566%

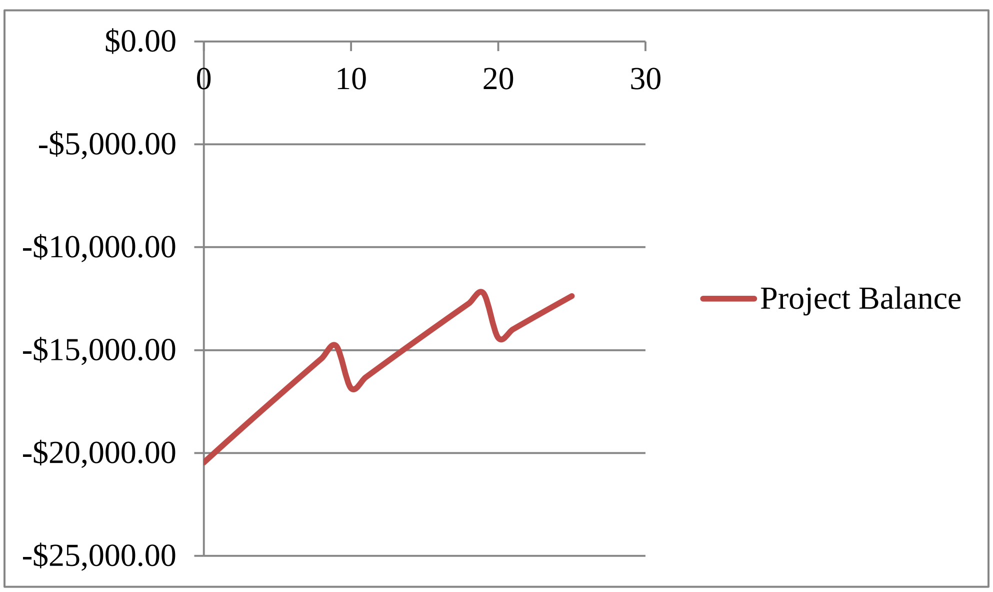

Figure 57: Project Balance for a Standard System at the First Location in Marion County

Marion County: Location #2

A standard system in the second location in Marion County generates 11035 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 58 shows the monthly generation of electricity in this area.

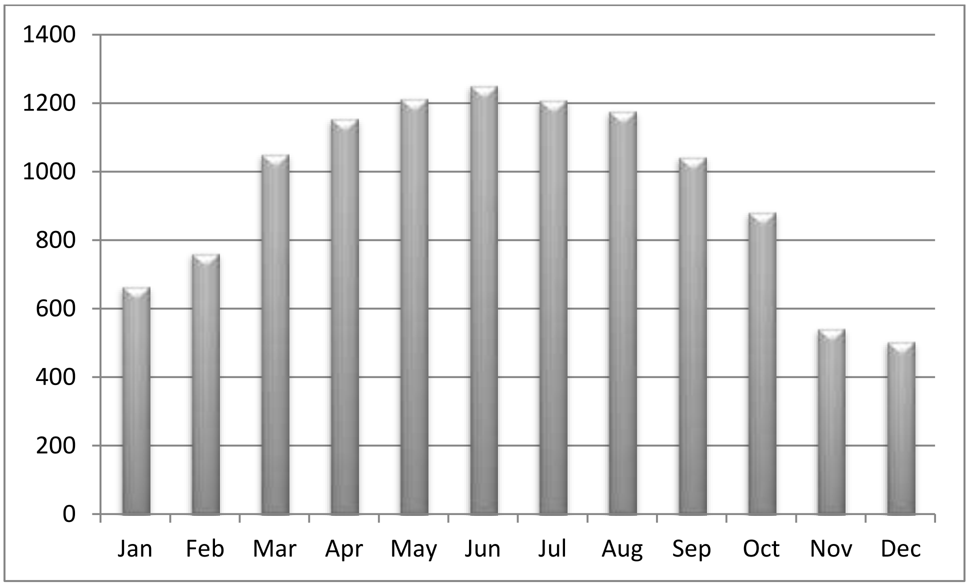

Figure 58: The Monthly Generation of Electricity in Marion County, Location #2

The project at the end of year 25 has -$14,884.85 as a balance. Figure 59 shows the project balance during the 25 years. According to these numbers, the NPV is equal to $12,970.39, which is less than the present value for the system ($20,468.59), the IRR is -1.324%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 26 summarizes the result of the economic assessment. Appendix C includes for more details about the cash flow, project balance, energy generation, and solar radiations.

Table 26

The Second Location in Marion County, Indiana

Station Identification	
Location:	2
County:	Marion County, Indiana
Latitude:	40.1 ° N
Longitude:	86.2 ° W
Generation Of Electricity kWh in the 1st year	11035 kWh
Energy Value $ in the 1st year	$1,153.74
PB	-$14,884.85
NPV	$12,970.39
IRR	-1.324%

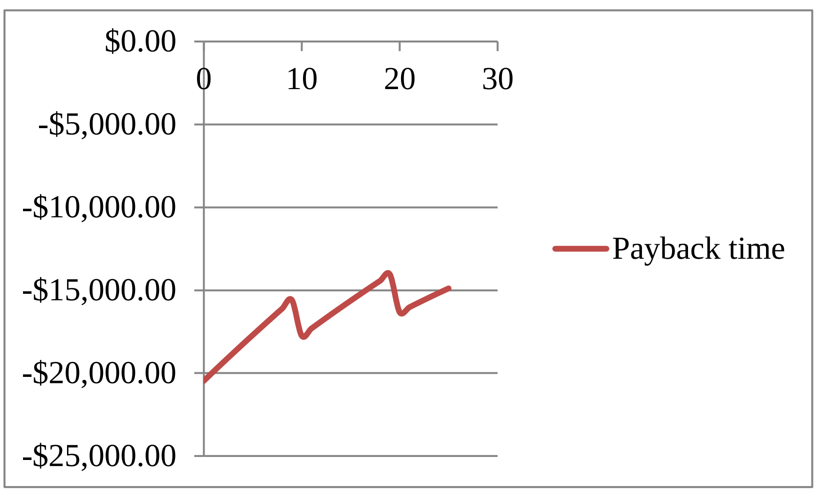

Figure 59: Project Balance for a Standard System at the Second Location in Marion County

Monroe County

Monroe County was selected to represent the South Central region. There are 19 zip codes serving this county. There are three different latitudes and longitudes used for the county:

the first location with latitude of 38.967, longitude of -86.022, and the electricity price is 10.379 cents/kWh. The second location with latitude of 39.298, longitude of -86.554, and the electricity price is 11.519 cents/kWh. The third location with latitude of 38.926, the longitude of -86.499, and the electricity price is 10.92 cents/kWh.

Monroe County: Location #1

A standard system in the first location in Monroe County generates 11319 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 60 shows the monthly generation of electricity in this area.

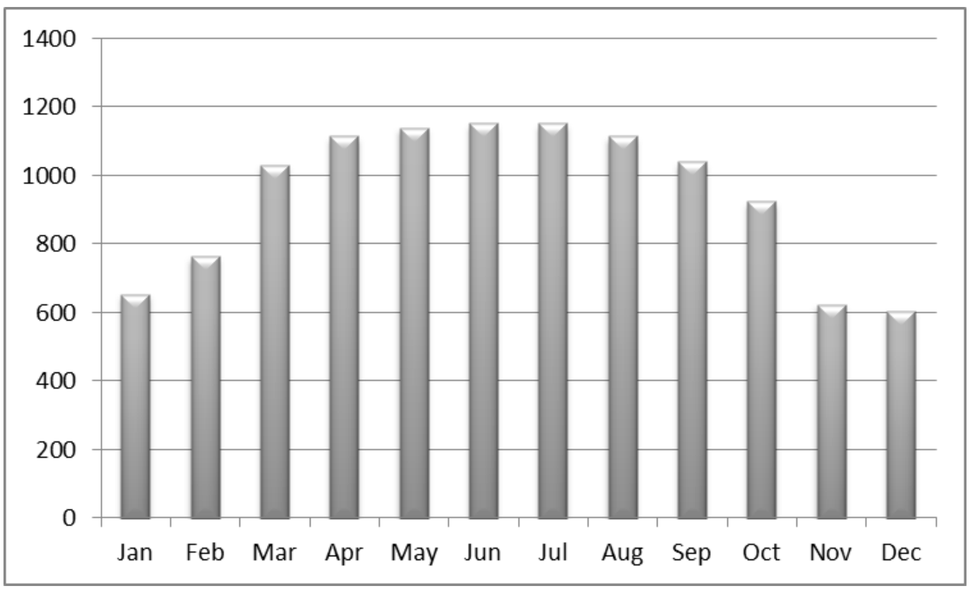

Figure 60: The Monthly Generation of Electricity in Monroe County, Location #1

A household in the location could save $1,257.04 in the first year. The project at the end of year 25 has -$11,437.39 as a balance. Figure 61shows the project balance during the 25 years. According to these numbers, the NPV is equal to $14,568.96, which is less than the present value for the system ($20,468.59), the IRR is -0.295%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 27 summarizes the result of the economic assessment. Appendix C includes more details about the cash flow, energy generation, and solar radiations.

Table 27

The First Location in Monroe County, Indiana

Station Identification	
Location:	1
County:	Monroe County, Indiana
Latitude:	39.0 ° N
Longitude:	86.0 ° W
Generation Of Elect. kWh in the 1st Year	11319 kWh
Energy Value $ in the 1st year	$1,257.04
PB	-$11,437.39
NPV	$14,568.96
IRR	-0.295%

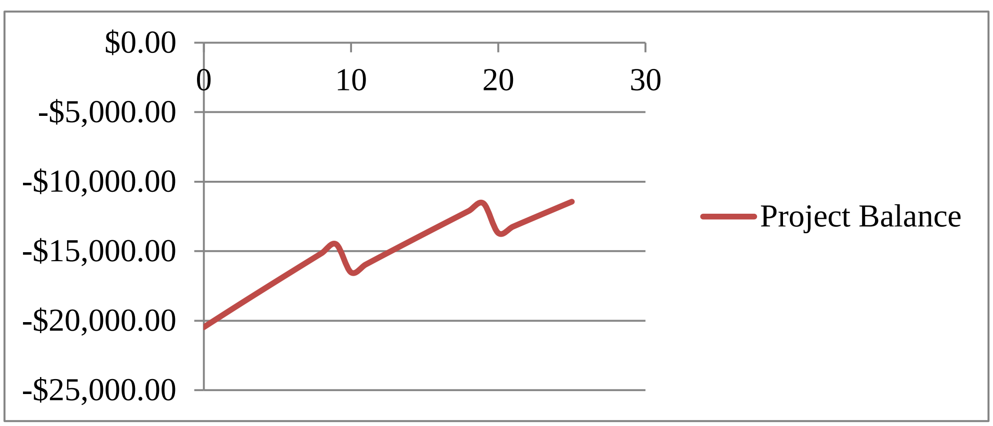

Figure 61: Project Balance for a Standard System at the First Location in Monroe County

Monroe County: Location #2

A standard system in the second location in Monroe County generates 11626 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 62 shows the monthly generation of electricity in this area.

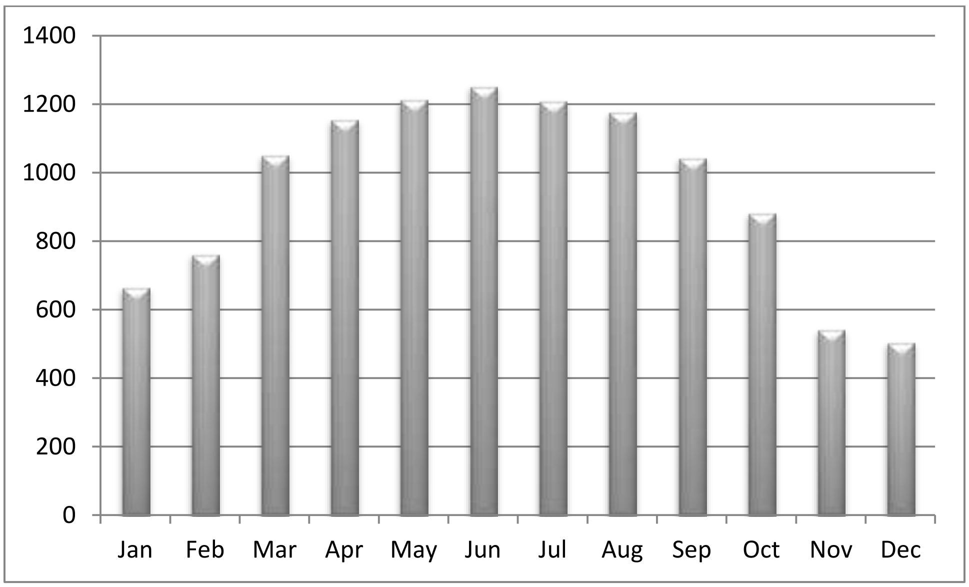

Figure 62: The Monthly Generation of Electricity in Monroe County, Location #2

Therefore, a household in this location could save $1,432.94 in the first year. The project at the end of year 25 has -$6,026.24as a balance. Figure 63 shows the project balance during the 25 years. According to these numbers, the NPV is equal to $17,078.08, which is less than the present value for the system ($20,468.59), the IRR is 1.186%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 28 summarizes the result of the economic assessment. Appendix C includes more details about the cash flow, project balance, energy generation, and solar radiations.

Table 28

The Second Location in Monroe County, Indiana

Station Identification	
Location:	2
County:	Monroe County, Indiana
Latitude:	39.3 ° N
Longitude:	86.6 ° W
Generation Of Electricity kWh in the 1st year	11626 kWh
Energy Value $ in the 1st year	$1,432.94
PB	-$6,026.24
NPV	$17,078.08
IRR	1.186%

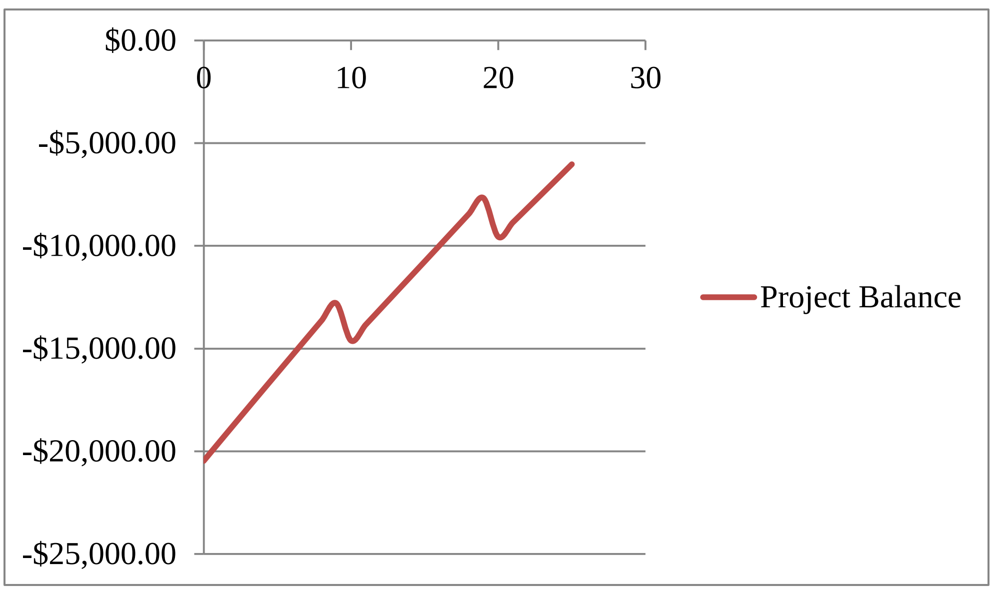

Figure 63: Project Balance for a Standard System at the Second Location in Monroe County

Monroe County: Location #3

A standard system in the third location in Monroe County generates 11297 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 64 shows the monthly generation of electricity in this area.

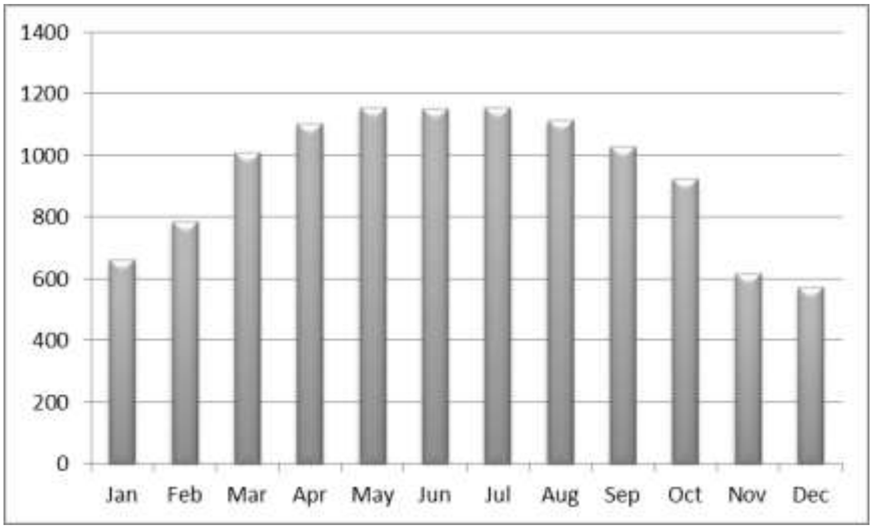

Figure 64: The Monthly Generation of Electricity in Monroe County, Location #3

A household in this location could save $1,319.98 in the first year. The project at the end of year 25 has -$9,501.03 as a balance. Figure 65 shows the project balance during the 25 years. According to these numbers, the NPV is equal to $15,466.84, which is less than the present value for the system ($20,468.59), the IRR is 0.252%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 29 summarizes the result of the economic assessment. Appendix C includes more details about the cash flow, energy generation, and solar radiations.

Table 29

The Third Location in Monroe County, Indiana

Station Identification	
Location:	3
County:	Monroe County, Indiana
Latitude:	38.9 ° N
Longitude:	86.5 ° W
Generation Of Electricity kWh in the 1st year	11297 kWh
Energy Value $ in the 1st year	$1,319.98
PB	-$9,501.03
NPV	$15,466.84
IRR	0.252%

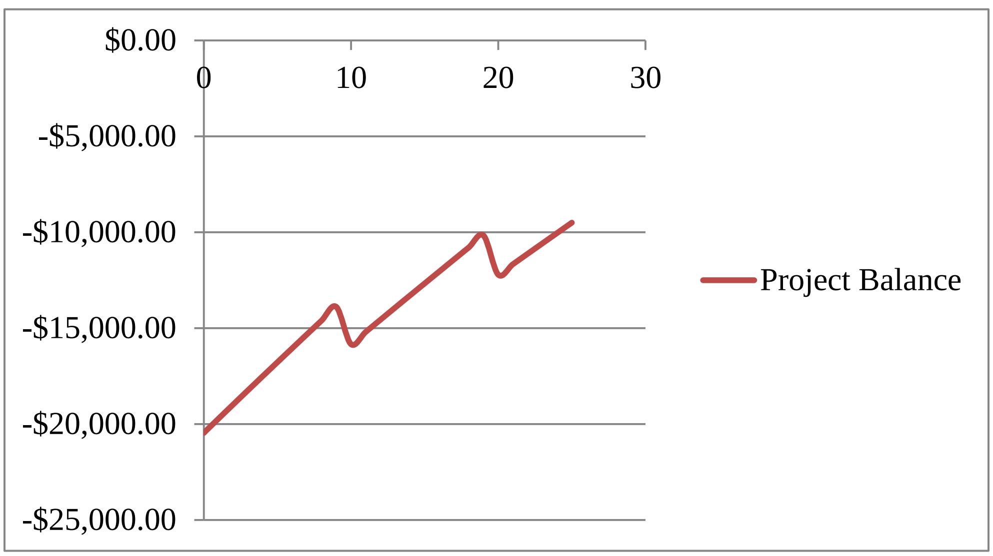

Figure 65: Project Balance for a Standard System at the Third Location in Monroe County

Vanderburgh County

Vanderburgh County was selected to represent the South region. There are 35 zip codes serving this county. There are two different latitudes and longitudes used for the county: the first location with latitude of 38.097, longitude of -87.33, and the electricity rate is 10.867 cents/kWh. The second location with latitude of 38.048, longitude of -87.797, and the electricity rate is 10.038 cents/kWh.

Vanderburgh County: Location #1

A standard system in the first location in Vanderburgh County generates 11543 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 66 shows the monthly generation of electricity in this area.

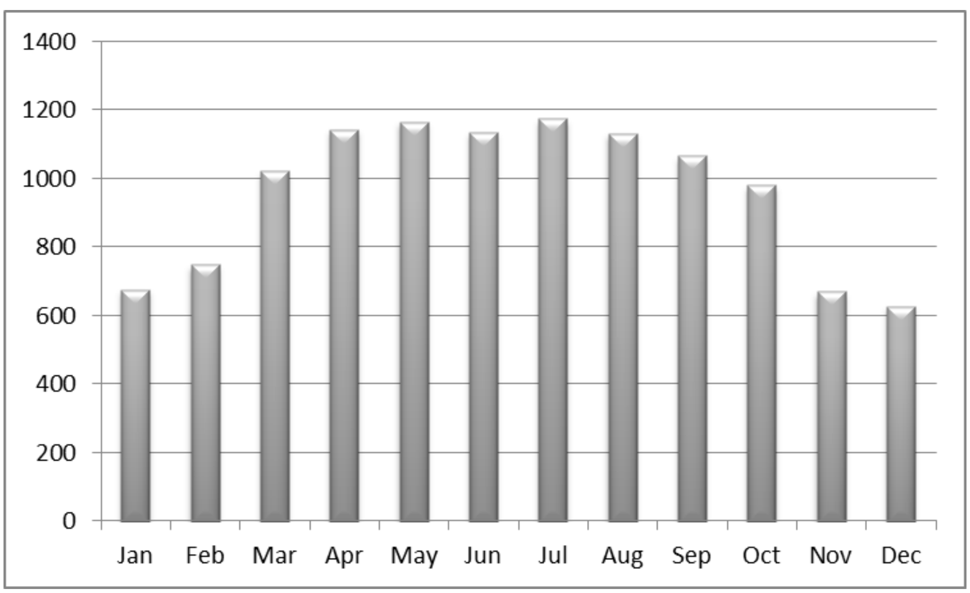

Figure 66: The Monthly Generation of Electricity in Vanderburgh County, Location #1

A household in this location could save $1,342.19 in the first year. The project at the end of year 25 has -$8,818.05 as a balance. Figure 67shows the project balance during the 25 years.

According to these numbers, the NPV is equal to $15,783.53, which is less than the present value for the system ($20,468.59), the IRR is 0.440%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 30 summarizes the result of the economic assessment. Appendix C includes more details about the cash flow, project balance, energy generation, and solar radiations.

Table 30

The First Location in Vanderburgh County, Indiana

Station Identification	
Location:	1
County:	Vanderburgh County , Indiana
Latitude:	38.1 ° N
Longitude:	87.3 ° W
Generation Of Elect. kWh in the 1^{st} Year	11543 kWh
Energy Value $ in the 1^{st} year	$1,342.19
PB	-$8,818.05
NPV	$15,783.53
IRR	0.440%

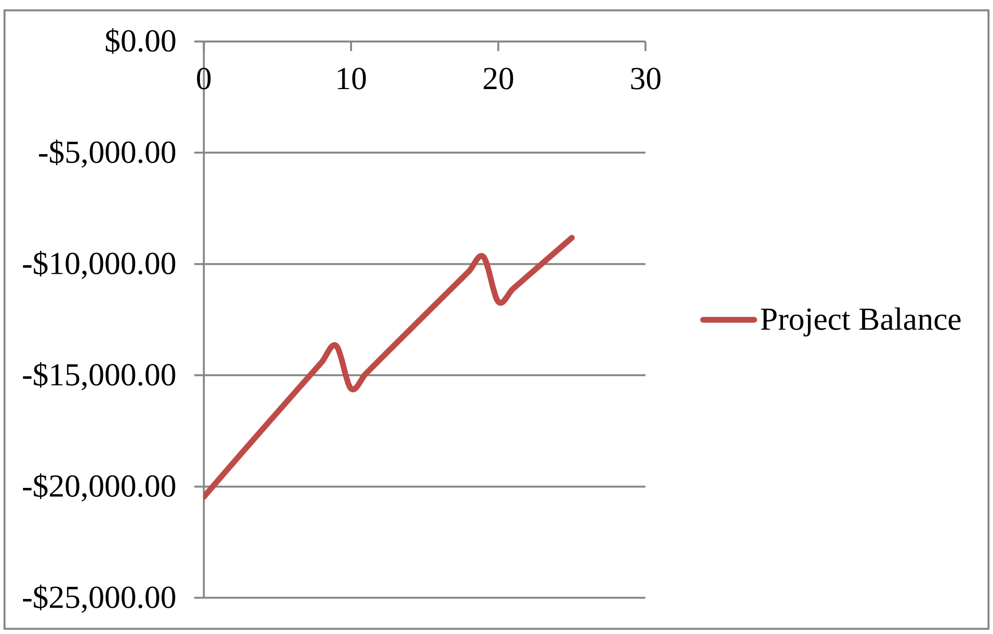

Figure 67: Project Balance for a Standard System at the First Location in Vanderburgh County

Vanderburgh County: Location #2

A standard system in the second location in Vanderburgh County generates 11942 kWh during the first year. After the first year, this amount is decreased by 3%/year due to degradation factor. Figure 68 shows the monthly generation of electricity in this area.

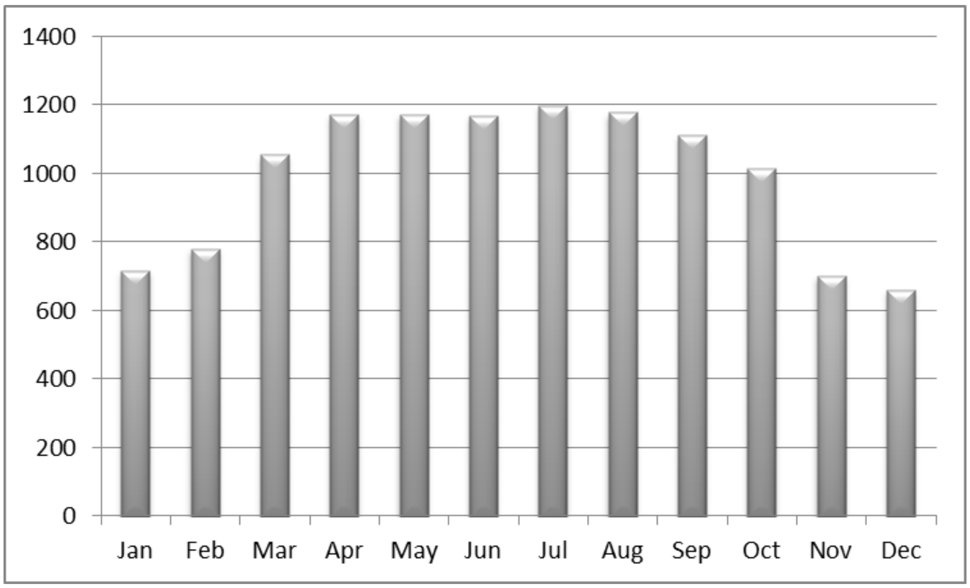

Figure 68: The Monthly Generation of Electricity in Vanderburgh County, Location #2

A household in this location could save $1,282.65 in the first year. The project at the end of year 25 has -$10,649.42 as a balance. Figure 69 shows the project balance during the 25 years. According to these numbers, the NPV is equal to $14,934.34, which is less than the present value for the system ($20,468.59), the IRR is -0.070%, which is less than MARR (3%), and the project balance is negative. Therefore, it can be concluded that installing a standard PV system in that area is not justified economically. Table 31 summarizes the result of the economic assessment. Appendix C includes for more details about the cash flow, project balance, energy generation, and solar radiations.

Table 31

The Second Location in Vanderburgh County, Indiana

Station Identification	
Location:	2
County:	Vanderburgh County, Indiana
Latitude:	38.0 ° N
Longitude:	87.8 ° W
Generation Of Elect. kWh in the 1st Year	11942 kWh
Energy Value $ in the 1st year	$1,282.65
PB	-$10,649.42
NPV	$14,934.34
IRR	-0.070%

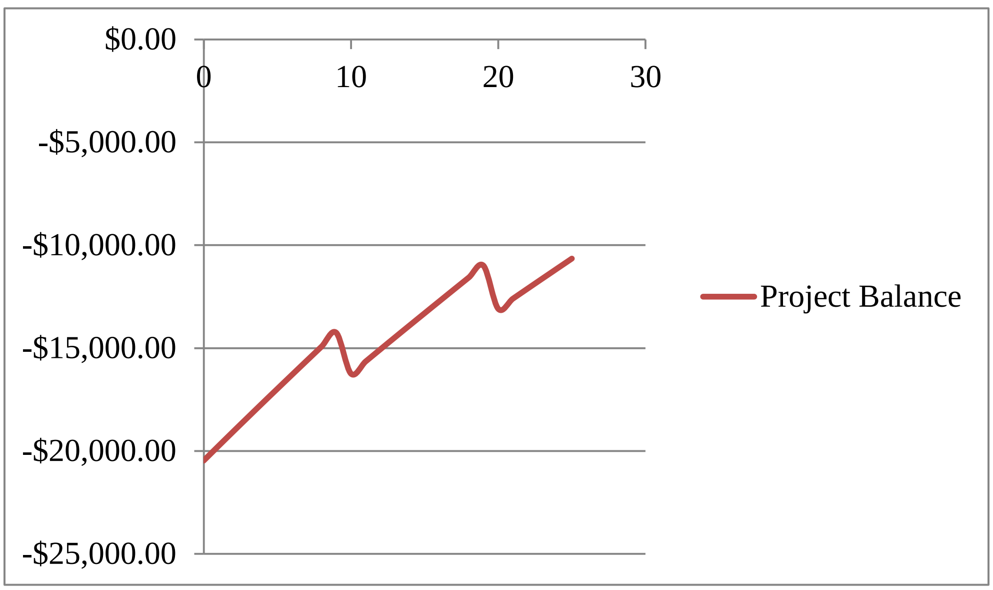

Figure 69: Project Balance for a Standard System at the Second Location in Vanderburgh County

Summary

This chapter has presented the findings of evaluating the financial feasibility of installing and using a standard residential grid-connected PV system in the State of Indiana. The findings were built by assessing a standard PV system economically in the selected six counties: Lake County was selected to represent the North region, Allen County was selected to represent the East region, Tippecanoe County was selected to represent the West region, Marion County was selected to represent the Central region, Monroe County was selected to represent the South Central region, and Vanderburgh County was selected to represent the South region. The assessment covered a total of eighteen locations: two in the Lake County, five locations in the Allen County, four locations in the Tippecanoe County, two locations in the Marion County, three locations in the Monroe County, and two locations in the Vanderburgh County.

The study findings are:

- The perfect size of the PV system that is suitable for a typical single family home in the State of Indiana is 9.36 KW.
- The average cost for a standard size of the PV system, which includes 36 panels, one inverter, nine rack systems, accessories (e.g. wires, connectors, breakers, and switches…), and installation is $29,240.84 ($25,869.60 +$2,589.96 +$781.28). The maximum cost for a standard PV system is $44,882.22 (4.45*9360+3089.5+140.72). The minimum cost is $16,727.02 (1.59*9360+1789.5+55.12). The average price was used in this study to calculate expected cash flows of the system.
- There is no maintenance required for the system but it is suggested that every 10 years a household buy a new inverter.

- Homeowners in the State of Indiana are eligible to receive a 30% federal tax credit. This reduced the average net cost for a standard system to \$20,468.59 (\$29,240.84 – \$8,772.252).
- A standard PV system produces about 11,000 kWh/ year. The system could eliminate the need for buying electricity by up to 100% because it generates all the electricity needed for a single household in the State of Indiana, and excess electricity could be sold back to the electric utility to offset power needed at night.
- The payback period and internal rate for a standard sized PV system varies from one area to another and depends mainly on the rates of electricity and the amount of electricity that could be generated at a specific area. The values of IRR range from -4.4270% to 1.186%, which are less than MARR (3%).
- The system does not produce a positive balance within the life time of the system (25 years).
- The results and the data illustrate that installation of the PV system in the State of Indiana is economically not justified and that the system will not pay for itself within 25 years assuming the average cost of a system.
- The areas with high solar potential are the cities located in Vanderburgh County with the coordinates of 38.0 ° N and 87.8 ° W. A standard system could generate 11942 kWh per year. These areas may be suitable for building and installing a commercial PV system in the State of Indiana.

The result of this study answers the research questions, and meets all of the study's objectives. The researcher was not able to reject the null hypothesis that installing a PV system for a single family residence in the State of Indiana will not pay for itself within 25 years assuming the average cost of a system. The government incentive programs are not enough to offset the cost of installing the system against the cost of the electricity that would not be purchased from the utility company. The private sector (e.g., manufacturers, electricity companies) with the government agencies (e.g., universities, public libraries, …) in the State of Indiana should work together to develop more effective plans and financial incentive programs to improve the PV sector in the state of Indiana. Even the system is not viable in Indiana but environmental benefits could be gained from installing the system. The government should create educational programs that help in improving the residents' awareness regarding the environmental benefits of installing a standard PV system.

Table 32 summarizes the result of the economic analysis for all the selected counties in the State of Indiana.

Table 32

Summary of the Study Result

County	Electricity rate	Generation Of Elec./ Year	Project Balance by end of year 25	NPV	IRR
Lake County, location 1	11.60	10864 kWh	-$8,632.74	$15,869.46	0.491%
Lake County, location 2	11.50	10935 kWh	-$8,746.96	$15,816.50	0.460%
Allen County, Location 1	7.30	10999 kWh	-$23,677.31	$8,893.37	-4.4270%
Allen County, Location 2	10.20	10880 kWh	-$13,642.66	$13,546.39	-0.9440%
Allen County, Location 3	9.90	10842 kWh	-$14,869.06	$12,977.71	-1.3190%
Allen County, Location 4	9.70	10890 kWh	-$15,429.92	$12,717.64	-1.4940%
Allen County, Location 5	10.00	11472 kWh	-$12,481.77	$14,084.69	-0.5980%
Tippecanoe County, Location 1	11.00	11043 kWh	-$10,290.32	$15,100.85	0.032%
Tippecanoe County, Location 2	10.70	11358 kWh	-$9,928.59	$15,268.58	0.133%

County	Electricity rate	Generation Of Elec./ Year	Project Balance by end of year 25	NPV	IRR
Tippecanoe County, Location 3	11.30	11277 kWh	-$8,140.01	$16,097.93	0.625%
Tippecanoe County, Location 4	10.90	11539 kWh	-$8,642.62	$15,864.88	0.488%
Marion County, Location 1	10.20	11194 kWh	-$12,372.82	$14,135.20	-0.5660%
Marion County, Location 2	9.70	11035 kWh	-$14,884.85	$12,970.39	-1.3240%
Monroe County, Location 1	10.40	11319 kWh	-$11,437.39	$14,568.96	-0.2950%
Monroe County, Location 2	11.50	11626 kWh	-$6,026.24	$17,078.08	1.186%
Monroe County, Location 3	10.90	11297 kWh	-$9,501.03	$15,466.84	0.2520%
Vanderburgh County, Location 1	10.90	11543 kWh	-$8,818.05	$15,783.53	0.440%
Vanderburgh County, Location 2	10.00	11942 kWh	-$10,649.42	$14,934.34	-0.0700%

Figure 70 summarizes the electricity that could be generated by a standard PV system in all of the selected locations.

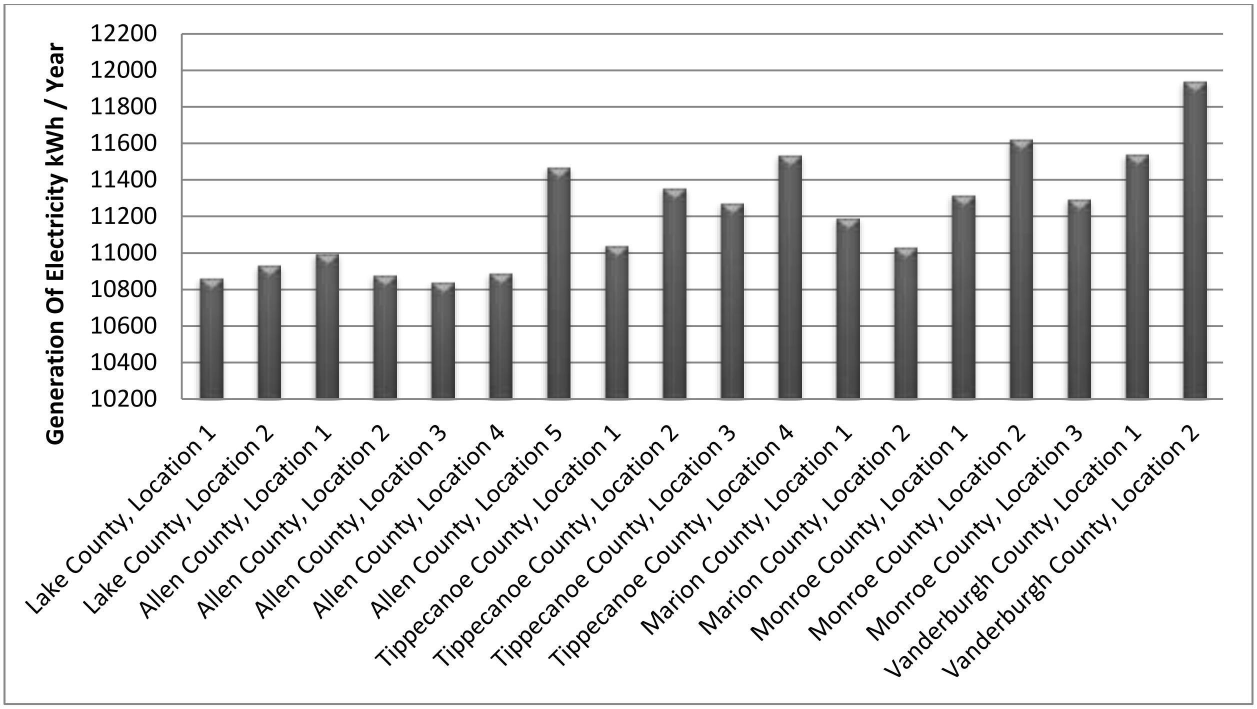

Figure 70: Electricity Generation by a Standard PV System in the Selected Locations.

It can be concluded that the cost of solar PV is higher than the market valuation of the power it produced; thus, solar PV did not compete on a cost basis with the traditional competitive energy sources. Reducing the capital cost will make the standard PV system economically viable. The study found that the capital cost for the system should be reduced by at least an additional 15% - 56%. Table 33 illustrates the reduction percentages that are needed in each area in order to make the system economically viable. Moreover, in the future, increasing electrical rates will continue to improve the feasibility of installing PV systems in the state of Indian.

Table 33

Further Reduction in the Cost to Make the System Economically Feasible

County, Location	Cost should be reduced by
Monroe County, Location 2	15%
Tippecanoe County, Location 3	19%
Tippecanoe County, Location 4	20%
Lake County, location 2	21%
Vanderburgh County, Location 1	21%
Lake County, location 1	22%
Monroe County, Location 3	23%
Tippecanoe County, Location 2	23%
Tippecanoe County, Location 1	24%
Vanderburgh County, Location 2	24%
Monroe County, Location 1	28%
Marion County, Location 1	29%
Allen County, Location 2	32%
Allen County, Location 3	35%
Marion County, Location 2	35%
Allen County, Location 4	36%
Allen County, Location 5	39%
Allen County, Location 1	56%

CHAPTER 5

SUMMARY AND DISCUSSION

The researcher designed this study to investigate the use, efficiency, and viability of residential photovoltaic (PV) grid-connected systems in the state of Indiana. The study may benefit not only the residents of Indiana but also the decision makers, who may be able to identify situations for using PV systems in the state as well as make decisions that help in meeting future challenges and creating economic growth.

Summary of Research Problem

This study aimed to measure the financial viability of installing and using a residential grid-connected PV system in the State of Indiana while predicting its performance in different geographical locations within the state over the system's expected lifetime.

The results of the analysis were used to answer the following research questions:

1. What is the precise size of a PV system suitable for a typical single family home in Indiana?
2. How much does a standard PV system cost?
3. How much electricity will a standard PV system produce?
4. By how much will a standard PV system reduce electricity expenses?

5. Is the standard PV system, without government subsidy support, financially attractive investments to Indiana homeowners?
6. Does the Federal tax credit make it a good investment?
7. What is the payback period for a standard PV system?
8. What is the internal rate of return for a standard PV system?
9. How will future electric rate increases impact financial metrics, specifically internal rate of return?

Summary of Method

Using a systematic approach consisting of six steps, data regarding the use of renewable energy in the State of Indiana was collected from the website of the US Department of Energy to perform feasibility analysis of the installation and use of a standard-sized residential PV system. The first step was conducting sample selection by identifying the most populous county in each of the six geographical regions into which the Indiana government organizes the counties of Indiana—North, East, West, Central, South Central, and South—and selecting it to serve as the representative county of that region. The second step was identifying the zip codes within each county using the Zip Code Finder application. The third step was using the Google Earth application to measure the solar azimuth and solar altitude for further specification of the geographical location for each zip code. The fourth step was contacting professionals who work in the PV industry to obtain important data and parameters regarding a standard PV system, including size, components, costs, maintenance, and expected lifetime. The fifth step was using the collected data as inputs for the PV Watt application to calculate the expected performance and electricity production of a standard PV system. The last step was analyzing the data collected from the PV Watt application using Microsoft Excel and then creating charts that summarize the findings.

Summary of Findings

The researcher was not able to reject the null hypothesis that installing a PV system for a single family residence in the State of Indiana will not pay for itself within 25 years. This study found that the standard PV system does not produce a positive balance and does not pay for itself within 25 years (the life time of the system) assuming the average cost of a system. The government incentive programs are not enough to offset the cost of installing the system against the cost of the electricity that would not be purchased from the utility company. It can be concluded that the cost of solar PV is higher than the market valuation of the power it produced; thus, solar PV did not compete on a cost basis with the traditional competitive energy sources. Reducing the capital cost will make the standard PV system economically viable. The study found that the capital cost for the system should be reduced by at least an additional 15% - 56%. The data analysis showed the following findings of this study:

- The perfect size of the PV system that is suitable for a typical single family home in the State of Indiana is 9.36 KW.
- The average cost for a standard size of the PV system, which includes 36 panels, one inverter, nine rack systems, accessories (e.g. wires, connectors, breakers, and switches…), and installation is $29,240.84 ($25,869.60 +$2,589.96 +$781.28). The maximum cost for a standard PV system is $44,882.22 (4.45*9360+3089.5+140.72). The minimum cost is $16,727.02 (1.59*9360+1789.5+55.12). The average price was used in this study to calculate expected cash flows of the system.

- There is no maintenance required for the system but it is suggested that every 10 years a household buy a new inverter. The average price for an inverter is $ 2,589.96.
- Homeowners in the State of Indiana are eligible to receive a 30% federal income tax credit. This reduced the average net cost for a standard system to-$20,468.59 ($29,240.84 – $8,772.252).
- Based on the data obtained using the U.S. Department of Energy PV Watt application, a performance calculator for on-grid PV systems, the standard PV system produces about 11,000 kWh/ year. The system generates all the electricity needed for a single household in the State of Indiana, and excess electricity could be sold back to the electric utility to offset power needed at night.
- The payback period and internal rate for the standard sized PV system varies from one area to another and depends mainly on the rates of electricity and the amount of electricity that could be generated at a specific area. The values of IRR range from -4.4270% to 1.186%, which are less than MARR (3%). Table 32, in chapter 4, summarizes the NPV and the IRR for the standard PV system in each location of the selected counties.
- The system does not produce a positive balance within the life time of the system (25 years).
- The results and the data illustrate that installation of the PV system is economically not justified and that the system will not pay for itself within 25 years assuming the average cost of a system.
- The areas with high solar potential are the cities located in Vanderburgh County with the coordinates of 38.0 ° N and 87.8 ° W. A standard system could generate 11942 kWh per

year. These areas may be suitable for building and installing a commercial PV system in the State of Indiana.

The private sector (e.g., manufacturers, electricity companies) with the government agencies (e.g., universities, public libraries, …) in the State of Indiana should work together to develop more effective plans and financial incentive programs to improve the PV sector in the state of Indiana.

Even though the system does not seem to be economically viable in Indiana, environmental benefits could be gained from installing the system. For example, previous studies compared PV solar generation versus coal-fueled generation; they estimated that, on an average, producing 1000 kWh of electricity with solar power reduces emissions by nearly 8 pounds of sulfur dioxide, 5 pounds of nitrogen oxides, and more than 1400 pounds of carbon dioxide (Ibrahimov, 2013). Therefore, installing a standard PV system will enable its owner to reduce emissions by nearly 88 (11*8) pounds of sulfur dioxide, 55 (11*5) pounds of nitrogen oxides, and more than 15400 (11*1400) pounds of carbon dioxide.

The government should create educational programs that help in improving the residents' awareness regarding the environmental benefits of installing the standard PV system. Improving the Indiana residents' awareness will support the U. S. Department of Energy's efforts in reducing energy shortages and reducing America's dependence on foreign oil. Indiana residents should know that energy efficiency is beneficial for themselves, beneficial for their cities, and beneficial for the nation and the world even without immediate financial benefit.

This study may help the resident of Indiana understand the inter-relationship between energy, economy, and environment. By installing a standard PV system, residents of Indiana might be able to make their state a healthier place that is suitable to raise their kids in healthy environments. In addition, energy efficiency and healthy environment are important factors that attract other people to live in the State of Indiana.

Financial factors are some of the challenges that affect the progress of adopting energy equipment such as PV systems. This research was designed to identify the financial needs that may help in making the standard PV system economically viable.

Conclusion

This study aimed to explore the economic feasibility of installing a residential PV system in the State of Indiana while considering the system's performance over its lifetime. It provides detailed information about installing a standard sized PV system in the State of Indiana and determines that installing a PV system in a single family residence in Indiana is economically not viable and it will not pay for itself within 25 years assuming the average cost of a system. The average net cost for a standard system is $20,468.588. The payback period and internal rate for the standard sized PV system varies from one area to another and depends mainly on the electricity rates and the amount of electricity that could be generated at a specific area.

The PV professionals in the State of Indiana estimated the standard size of a PV system suitable for a single family home in Indiana, to be 9.36 KW. The system consists of 36 panels of 260 W each and enables a household to generate 11,000 kWh per year. The cost of the PV panels ranges from $1.59 to $4.45 per Watt. The average cost for installing a 9.36 kW system is $ 2.76 per Watt. From the online quotes, the researcher found that the PV manufacturers in the State of Indiana provide a warranty of 25 years for the panels and 10 years for the inverter. The price of the inverter ranges from $ 1,789.5 to $ 3,089.5. The average price for an inverter is $ 2,589.96. •

The average cost for a standard size of the PV system, which includes 36 panels, one inverter, nine rack systems, accessories (e.g. wires, connectors, breakers, and switches…), and installation is $29,240.84 ($25,869.60 +$2,589.96 +$781.28). The maximum cost for a standard PV system is $44,882.22 (4.45*9360+3089.5+140.72). The minimum cost is $16,727.02 (1.59*9360+1789.5+55.12). The average price was used in this study to calculate expected cash flows of the system. There is no maintenance required for the system but it is suggested that a household buy a new inverter every 10 years.

It has been found that the cost of solar PV is higher than the market valuation of the power it produced; thus, solar PV cannot compete on a cost basis with the traditional competitive energy sources such as coal. Reducing the capital cost will make the standard PV system economically viable. The study found that the capital cost for the system should be reduced by at least an additional 15% - 56%. Finally, in the future, increasing electrical rates will continue to improve the feasibility of installing PV systems in the state of Indiana.

Recommendations for Future Research

Based on the findings and conclusions, the following recommendations are made:

1- This study only considers the real increase in electricity prices during the period between 2005-2011 without considering the impact of the new EPA regulations. Future researchers might consider the impact of the new EPA regulations that affect the prices of coal-fueled electricity.

2- Developing online surveys and phone interviews in additional to the online quoting might be considered in the future to expand the pool of Indiana PV professionals who might be interested in participating in this study.

3- The researcher used the PV Watt application to calculate the amount of energy that can be produced using a standard PV system. Other simulations programs such as System Advisor Model could be used to verify the accuracy of the results.

4- Future study could be designed to investigate the benefits of building a commercial PV system in Vanderburgh County since this county has the highest solar potential in the state of Indiana.

5- This research has identified the financial needs for installing a standard PV system. Future research could include developing a survey, based on these identified needs, in order to find other factors that should be considered in developing the PV sector in Indiana.

6- Expansion of this study can be made by including all of the states in the United States. The expansion can be realized and conclusions drawn for the entire country.

7- The researcher recommends developing a future study to investigate the viability of one-axis and two axis PV grid-connected system and compare the result with the result of this study in order to develop a comprehensive picture for the viability of different types of PV systems.

8- Comparison study might be conducted to look at financial difference between the use of residential PV systems and residential wind turbines.

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APPENDIX A: ZIP CODES AND CITIES IN THE SELECTED COUNTIES

The following tables summarize the zip codes for the counties that have been selected for this study:

Table 34

ZIP Codes Serving the County of Lake, Indiana

Zip code	City	Zip code	City
46303	Cedar Lake	46356	Lowell
46307	Crown Point	46373	Saint John
46308	Crown Point	46375	Schererville
46311	Dyer	46376	Schneider
46312	East Chicago	46377	Shelby
46319	Griffith	46394	Whiting
46320	Hammond	46401	Gary
46321	Munster	46402	Gary
46322	Highland	46403	Gary
46323	Hammond	46404	Gary
46324	Hammond	46405	Lake Station
46325	Hammond	46406	Gary
46327	Hammond	46407	Gary
46341	Hebron	46408	Gary
46342	Hobart	46409	Gary
46355	Leroy	46410	Merrillville

Table 35

ZIP Codes Serving the County of Allen, Indiana

Zip code	City	Zip code	City
46704	Arcola	46816	Fort Wayne
46723	Churubusco	46818	Fort Wayne
46741	Grabill	46819	Fort Wayne
46743	Harlan	46825	Fort Wayne
46745	Hoagland	46835	Fort Wayne
46748	Huntertown	46845	Fort Wayne
46765	Leo	46850	Fort Wayne
46773	Monroeville	46851	Fort Wayne
46774	New haven	46852	Fort Wayne
46777	Ossian	46853	Fort Wayne
46783	Roanoke	46854	Fort Wayne
46788	Spencerville	46855	Fort Wayne
46797	Woodburn	46856	Fort Wayne
46798	Yoder	46857	Fort Wayne
46799	Zanesville	46858	Fort Wayne
46801	Fort Wayne	46859	Fort Wayne
46802	Fort Wayne	46860	Fort Wayne
46803	Fort Wayne	46861	Fort Wayne
46804	Fort Wayne	46862	Fort Wayne
46805	Fort Wayne	46863	Fort Wayne
46806	Fort Wayne	46864	Fort Wayne
46807	Fort Wayne	46865	Fort Wayne
46808	Fort Wayne	46866	Fort Wayne
46809	Fort Wayne	46867	Fort Wayne
46814	Fort Wayne	46868	Fort Wayne
46815	Fort Wayne	46869	Fort Wayne

Table 36

ZIP Codes Serving the County of Tippecanoe, Indiana

Zip code	City
47901	Lafayette
47902	Lafayette
47903	Lafayette
47904	Lafayette
47905	Lafayette
47906	West Lafayette
47907	West Lafayette
47909	Lafayette
47920	Battle Ground
47924	Buck Creek
47930	Clarks Hill
47941	Dayton
47955	Linden
47962	Montmorenci
47967	New Richmond
47970	Otterbein
47981	Romney
47983	Stockwell
47992	Westpoint
47994	Wingate
47996	West Lafayette

Table 37

ZIP Codes Serving the County of Marion, Indiana

Zip code	City		
46107	Beech Grove	46228	Indianapolis
46113	Camby	46229	Indianapolis
46183	West Newton	46230	Indianapolis
46201	Indianapolis	46231	Indianapolis
46202	Indianapolis	46234	Indianapolis
46203	Indianapolis	46235	Indianapolis
46204	Indianapolis	46236	Indianapolis
46205	Indianapolis	46237	Indianapolis
46206	Indianapolis	46239	Indianapolis
46207	Indianapolis	46240	Indianapolis
46208	Indianapolis	46241	Indianapolis
46209	Indianapolis	46242	Indianapolis
46211	Indianapolis	46244	Indianapolis
46213	Indianapolis	46247	Indianapolis
46214	Indianapolis	46249	Indianapolis
46216	Indianapolis	46250	Indianapolis
46217	Indianapolis	46251	Indianapolis
46218	Indianapolis	46253	Indianapolis
46219	Indianapolis	46254	Indianapolis
46220	Indianapolis	46255	Indianapolis
46221	Indianapolis	46256	Indianapolis
46222	Indianapolis	46259	Indianapolis
46224	Indianapolis	46260	Indianapolis
46225	Indianapolis	46262	Indianapolis
46226	Indianapolis	46266	Indianapolis
46227	Indianapolis	46268	Indianapolis

Table 38

ZIP Codes Serving the County of Monroe, Indiana

Zip code	City
47264	Norman
47401	Bloomington
47402	Bloomington
47403	Bloomington
47404	Bloomington
47405	Bloomington
47406	Bloomington
47407	Bloomington
47408	Bloomington
47426	Clear creek
47429	Ellettsville
47433	Gosport
47434	Harrodsburg
47436	Heltonville
47458	Smithville
47462	Springville
47463	Stanford
47464	Stinesville
47468	Unionville

Table 39

ZIP Codes Serving the County of Vanderburgh, Indiana

Zip code	City
47618	Inglefield
47633	Poseyville
47639	Haubstadt
47701-08	Evansville
47710-25	Evansville
47728	Evansville
47730	Evansville
47731	Evansville
47732	Evansville
47733	Evansville
47734	Evansville
47735	Evansville
47736	Evansville
47737	Evansville
47740	Evansville
47747	Evansville
47750	Evansville

APPENDIX B: PV PROFESSIONALS IN THE STATE OF INDIANA

This appendix shows the contact information for the PV professionals in the State of Indiana. The information has been summarized in Table 40.

Table 40

PV Professional Contact Information in Indiana

Name	Business Type	City	Telephone
Solar Energy Systems, LLC	Retail sales, wholesale supplier, distributor, and electric utility	Nappanee, IN, 46550	574-773-0546
Bowen Engineering	General Contractor	Fishers, IN, 46038	317-842-2616
BPM Service Today	Contractor	Kendallville, IN, 46755	260-347-9388
Concept Beyond Tomorrow	Retail sales	Chesterton, IN , 46304	219-929-1397
CoolSpell, LLC.	Retail sales and wholesale supplier	Indianapolis, IN, 46220	317-201-4435
Earth-SOLAR Technologies Corporation	Photovoltaic Cell and Manufacturer	Indianapolis, IN, 46202	317. 926. 7000
G-Tech Energy, Inc.	Retail sales and site survey/assessment	Indianapolis, IN, 46220	317-627-3031
EcoSource Inc	Wholesale supplier	Columbus, IN, 47201	812-342-7226

Name	Business Type	City	Telephone
Estes Design & Manufacturing, Inc.	Manufacturer	Indianapolis, IN, 46229	317-899-2203
Green Alternatives	Retail sales	Kokomo, IN, 46902	765-480-4138
Greenworks Energy	Retail sales, wholesale supplier, importer, distributor, and mfg	Yorktown, IN, 47396	877-365-POWER
Hoagland Electric Inc.	Electrical Contracting	Wayne, IN, 46818	260-489-5990
Home Energy LLC	Retail sales, contractor, and wholesale supplier	Middlebury, IN, 46540	574-825-4800
Hurshtown Alternative Power	Retail sales and wholesale supplier	Grabill, IN, 46741-9617	260-438-5250
Illiana Power Corporation	Solar energy Consulting, design and installation	Terre Haute, IN, 47802	888-815-8023
Inovateus Solar LLC	Wholesale supplier and distributor	South Bend, IN, 46637	574-485-1405
Mann Plumbing Inc	Retail sales	Bloomington,	812-334-4003
MPI Solar		IN, 47404	812-327-8476
Morton Solar & Wind, LLC	Renewable Energy Products and Services	Evansville, IN, 47711	812-402-0900
Next Generation Resources, LLC	Retail sales	Grabill, IN, 46741	260-437-6490
Phoenix Mechanical	Consulting, design, and installation	Garrett, IN, 46738	260-357-1930

Name	Business Type	City	Telephone
Renewable Energy Systems, LLC	Design, installation, project development services, and contractor services	Avilla, IN, 46710	260-897-2450
SAVER	Retail sales, wholesale supplier, and exporter	Indianapolis, IN, 46239	317-465-8496
Solar Wind Energy Corporation	Design, installation, construction, contractor services, maintenance and repair services	Kendallville, IN, 46755	260-347-8382
Southside Attic Solution	Retail sales	Greenwood, IN, 46142	317-847-4546
SunRise Solar Inc	Manufacturer, wholesale supplier	St. John, IN, 46373	219-306-8163
SunWind Power Systems, Inc	Solar and wind Installation, design, and consulting	Floyds Knobs, IN, 47119	
One Planet Solar and Wind Inc.	Retail sales	Terre Haute, IN, 47807	812-235-1380
Strong Tower Roofing & Construction	Installation and maintenance	Springville, IN, 47462	812 - 797-0630
Lindley Heating & Cooling Inc.	Retail sales	Pittsboro, IN, 46167	317- 892-6024
Midwest Solar Additions	Installation, design, and consulting	Hebron, IN, 46341	219-996-7214

Name	Business Type	City	Telephone
Ameresco Energy Services	Retail sales	Indianapolis, IN, 46240	317- 816-0990
480v Solar	Installation, design, and consulting	Michigan City, IN, 46360	219- 879-5501
PrimeStar Solar	Installation and maintenance	Indianapolis, IN, 46229	317- 899-3000
J J J Enterprises	Retail sales	Indianapolis, IN, 46221	317-856-4744
Yager Electric	Retail sales	Fort Wayne, IN, 46818	260-710-2707
Solar Systems of Indiana	Installation, design, and consulting	Bloomington, IN, 47408	812- 336-2785
Midwest Wind and Solar LLC	Installation, design, and consulting	Merrillville, IN, 46411	219-714-2488
Solar Century of Indiana	Installation, design, and consulting	Indianapolis, IN, 46201	317-546-5071
Fair & Square Construction	Retail sales and installation	Poland, IN, 47868	812-821-0526
L & S Electric Co Inc	Retail sales and installation	Hammond, IN, 46327	219-932-8504
Solar Electric Turbine Co	Installation, design, and consulting	Westfield, IN, 46074	317-985-5685
Solar Energy Systems	Installation services	Shipshewana, IN, 46565	260-768-7275
BP Solar	Installation, design, and consulting	Whiting, IN, 46394	219-473-2867
Solartek Energy	Installation	Jeffersonville, IN, 47130	812-282-4601
Solar and Wind Wave	Installation	Indianapolis, IN	317-641-4610

Name	Business Type	City	Telephone
Solar Tek Energy	Retail sales	Newburgh, IN, 47630	812-853-5385
ERMCO, Inc. Electrical & Communications Contractors	Retail sales	Indianapolis, IN, 46217	317-780-2923

APPENDIX C: SYSTEM ECONOMIC ANALYSIS

Table 41

Monthly generation of electricity at the first location in the Lake County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.83	658
2	3.68	765
3	4.34	969
4	5.26	1094
5	5.71	1173
6	5.84	1142
7	5.73	1133
8	5.31	1058
9	4.92	963
10	4.00	850
11	2.49	527
12	2.37	532
Year	4.38	10864

Table 42

Cash flows and project balances for a standard system at the first location in the Lake County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	15	$1,019.04	-$12,195.79
1	$1,348.21	-$19,693.99	16	$998.87	-$11,532.84
2	$1,321.52	-$18,923.64	17	$979.09	-$10,870.36
3	$1,295.36	-$18,157.13	18	$959.71	-$10,207.96
4	$1,269.72	-$17,394.03	19	$940.71	-$9,545.27
5	$1,244.58	-$16,633.93	20	-$1,667.87	-$11,549.53
6	$1,219.95	-$15,876.40	21	$903.84	-$10,965.06
7	$1,195.80	-$15,121.02	22	$885.95	-$10,381.49
8	$1,172.13	-$14,367.36	23	$868.41	-$9,798.47
9	$1,148.92	-$13,614.99	24	$851.22	-$9,215.67
10	-$1,463.78	-$15,531.14	25	$834.37	-$8,632.74
11	$1,103.89	-$14,860.07			
12	$1,082.03	-$14,191.38			
13	$1,060.61	-$13,524.68			
14	$1,039.62	-$12,859.62			

Table 43

Monthly generation of electricity at the second location in the Lake County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.74	638
2	3.57	744
3	4.35	970
4	5.33	1106
5	5.78	1187
6	5.94	1160
7	5.76	1140
8	5.36	1068
9	4.97	974
10	4.11	875
11	2.56	541
12	2.37	533
Year	4.41	10935

Table 44

Cash flows and project balances for a standard system at the second location in the Lake County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	16	$996.12	-$11,600.30
1	$1,344.50	-$19,697.81	17	$976.40	-$10,942.62
2	$1,317.88	-$18,931.33	18	$957.07	-$10,285.12
3	$1,291.79	-$18,168.72	19	$938.12	-$9,627.41
4	$1,266.22	-$17,409.57	20	-$1,670.41	-$11,636.75
5	$1,241.16	-$16,653.47	21	$901.35	-$11,057.46
6	$1,216.59	-$15,899.99	22	$883.51	-$10,479.18
7	$1,192.50	-$15,148.71	23	$866.02	-$9,901.55
8	$1,168.90	-$14,399.20	24	$848.87	-$9,324.26
9	$1,145.76	-$13,651.05	25	$832.07	-$8,746.96
10	-$1,466.88	-$15,571.47			
11	$1,100.85	-$14,904.74			
12	$1,079.05	-$14,240.46			
13	$1,057.69	-$13,578.25			
14	$1,036.76	-$12,917.73			
15	$1,016.23	-$12,258.55			

Table 45

Monthly generation of electricity at the first location in the Allen County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.76	644
2	3.48	735
3	4.43	990
4	5.09	1078
5	5.81	1201
6	6.18	1215
7	5.92	1184
8	5.58	1119
9	5.15	1029
10	3.90	833
11	2.51	526
12	2.02	446
Year	4.41	10999

Table 46

Cash flows and project balances for a standard system at the first location in the Allen County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	17	$623.92	-$20,389.87
1	$859.14	-$20,197.74	18	$611.57	-$20,371.65
2	$842.13	-$19,936.28	19	$599.46	-$20,365.36
3	$825.46	-$19,684.14	20	-$2,002.37	-$23,038.76
4	$809.12	-$19,441.28	21	$575.96	-$23,136.68
5	$793.10	-$19,207.62	22	$564.56	-$23,249.28
6	$777.40	-$18,983.13	23	$553.39	-$23,376.77
7	$762.01	-$18,767.75	24	$542.43	-$23,519.37
8	$746.93	-$18,561.45	25	$531.69	-$23,677.31
9	$732.14	-$18,364.19			
10	-$1,872.31	-$20,843.59			
11	$703.44	-$20,744.36			
12	$689.52	-$20,656.49			
13	$675.87	-$20,580.04			
14	$662.49	-$20,515.08			
15	$649.37	-$20,461.68			
16	$636.52	-$20,419.91			

Table 47

Monthly generation of electricity at the second location in the Allen County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.57	596
2	3.26	678
3	4.46	999
4	5.27	1104
5	5.67	1168
6	6.14	1202
7	5.92	1177
8	5.63	1121
9	5.05	999
10	3.98	845
11	2.52	524
12	2.11	467
Year	4.39	10880

Table 48

Cash flows and project balances for a standard system at the second location in the Allen County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	16	$878.20	-$14,492.28
1	$1,185.35	-$19,861.74	17	$860.82	-$14,040.40
2	$1,161.88	-$19,260.85	18	$843.78	-$13,592.52
3	$1,138.88	-$18,665.63	19	$827.07	-$13,148.41
4	$1,116.34	-$18,075.77	20	-$1,779.26	-$15,375.50
5	$1,094.24	-$17,490.98	21	$794.65	-$15,018.27
6	$1,072.58	-$16,910.96	22	$778.92	-$14,666.53
7	$1,051.34	-$16,335.40	23	$763.50	-$14,320.12
8	$1,030.53	-$15,764.02	24	$748.39	-$13,978.88
9	$1,010.13	-$15,196.50	25	$733.58	-$13,642.66
10	-$1,599.82	-$17,300.21			
11	$970.54	-$16,819.57			
12	$951.32	-$16,344.29			
13	$932.49	-$15,874.15			
14	$914.03	-$15,408.92			
15	$895.94	-$14,948.38			

Table 49

Monthly generation of electricity at the third location in the Allen County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.63	611
2	3.38	705
3	4.43	993
4	5.22	1096
5	5.67	1169
6	6.11	1198
7	5.91	1176
8	5.62	1120
9	4.99	988
10	3.91	831
11	2.42	505
12	2.03	449
Year	4.37	10842

Table 50

Cash flows and project balances for a standard system at the third location in the Allen County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	17	$831.87	-$14,816.41
1	$1,145.48	-$19,902.80	18	$815.40	-$14,421.04
2	$1,122.80	-$19,343.40	19	$799.26	-$14,030.44
3	$1,100.58	-$18,790.11	20	-$1,806.52	-$16,312.07
4	$1,078.79	-$18,242.66	21	$767.93	-$16,010.47
5	$1,057.43	-$17,700.78	22	$752.72	-$15,715.48
6	$1,036.50	-$17,164.21	23	$737.82	-$15,426.98
7	$1,015.98	-$16,632.67	24	$723.22	-$15,144.88
8	$995.87	-$16,105.91	25	$708.90	-$14,869.06
9	$976.16	-$15,583.64			
10	-$1,633.13	-$17,733.27			
11	$937.89	-$17,299.24			
12	$919.33	-$16,871.31			
13	$901.13	-$16,449.29			
14	$883.29	-$16,032.98			
15	$865.80	-$15,622.19			
16	$848.67	-$15,216.73			

Table 51

Monthly generation of electricity at the fourth location in the Allen County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.56	591
2	3.26	677
3	4.46	996
4	5.28	1105
5	5.71	1174
6	6.18	1207
7	5.94	1180
8	5.65	1124
9	5.08	1004
10	3.97	842
11	2.52	524
12	2.11	466
Year	4.40	10890

Table 52

Cash flows and project balances for a standard system at the fourth location in the Allen County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	16	$835.16	-$15,548.04
1	$1,127.25	-$19,921.58	17	$818.62	-$15,171.30
2	$1,104.93	-$19,381.15	18	$802.42	-$14,799.95
3	$1,083.06	-$18,847.04	19	$786.53	-$14,433.81
4	$1,061.62	-$18,318.98	20	-$1,819.00	-$16,740.39
5	$1,040.60	-$17,796.73	21	$755.70	-$16,464.23
6	$1,020.00	-$17,280.03	22	$740.74	-$16,195.19
7	$999.81	-$16,768.62	23	$726.08	-$15,933.18
8	$980.02	-$16,262.26	24	$711.71	-$15,678.12
9	$960.62	-$15,760.69	25	$697.62	-$15,429.92
10	-$1,648.36	-$17,931.32			
11	$922.96	-$17,518.61			
12	$904.69	-$17,112.33			
13	$886.78	-$16,712.31			
14	$869.23	-$16,318.37			
15	$852.02	-$15,930.34			

Table 53

Monthly generation of electricity at the fifth location in the Allen County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.87	666
2	3.66	763
3	4.70	1053
4	5.50	1156
5	5.89	1215
6	6.39	1254
7	6.08	1211
8	5.90	1178
9	5.27	1044
10	4.16	884
11	2.61	544
12	2.28	505
Year	4.61	11472

Table 54

Cash flows and project balances for a standard system at the fifth location in the Allen County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	17	$888.22	-$13,305.84
1	$1,223.08	-$19,822.87	18	$870.64	-$12,808.26
2	$1,198.87	-$19,182.71	19	$853.41	-$12,313.49
3	$1,175.14	-$18,547.80	20	-$1,753.45	-$14,488.95
4	$1,151.88	-$17,917.80	21	$819.95	-$14,079.06
5	$1,129.08	-$17,292.39	22	$803.72	-$13,673.60
6	$1,106.73	-$16,671.23	23	$787.81	-$13,272.36
7	$1,084.82	-$16,054.01	24	$772.22	-$12,875.15
8	$1,063.34	-$15,440.38	25	$756.93	-$12,481.77
9	$1,042.29	-$14,830.03			
10	-$1,568.30	-$16,890.28			
11	$1,001.44	-$16,365.51			
12	$981.61	-$15,845.42			
13	$962.18	-$15,329.74			
14	$943.13	-$14,818.20			
15	$924.46	-$14,310.55			
16	$906.16	-$13,806.52			

Table 55

Monthly generation of electricity at the first location in the Tippecanoe County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.72	639
2	3.52	736
3	4.42	976
4	5.36	1108
5	5.74	1177
6	6.05	1166
7	5.87	1154
8	5.50	1097
9	5.07	998
10	4.21	893
11	2.69	568
12	2.35	531
Year	4.46	11043

Table 56

Cash flows and project balances for a standard system at the first location in the Tippecanoe County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	17	$939.96	-$11,919.19
1	$1,294.33	-$19,749.49	18	$921.35	-$11,327.77
2	$1,268.70	-$19,035.21	19	$903.12	-$10,737.40
3	$1,243.59	-$18,325.37	20	-$1,704.72	-$12,815.38
4	$1,218.97	-$17,619.59	21	$867.71	-$12,306.10
5	$1,194.84	-$16,917.49	22	$850.54	-$11,799.23
6	$1,171.19	-$16,218.69	23	$833.70	-$11,294.50
7	$1,148.00	-$15,522.81	24	$817.20	-$10,791.62
8	$1,125.28	-$14,829.46	25	$801.02	-$10,290.32
9	$1,103.00	-$14,138.25			
10	-$1,508.79	-$16,116.45			
11	$1,059.77	-$15,508.39			
12	$1,038.79	-$14,903.69			
13	$1,018.22	-$14,302.03			
14	$998.07	-$13,703.08			
15	$978.31	-$13,106.51			
16	$958.94	-$12,511.99			

Table 57

Monthly generation of electricity at the second location in the Tippecanoe County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.89	678
2	3.67	764
3	4.55	1002
4	5.46	1126
5	5.88	1204
6	6.14	1182
7	5.99	1175
8	5.64	1123
9	5.25	1030
10	4.37	923
11	2.80	592
12	2.48	561
Year	4.60	11358

Table 58

Cash flows and project balances for a standard system at the second location in the Tippecanoe County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	17	$948.50	-$11,690.31
1	$1,306.08	-$19,737.38	18	$929.72	-$11,083.40
2	$1,280.23	-$19,010.86	19	$911.32	-$10,477.24
3	$1,254.89	-$18,288.65	20	-$1,696.68	-$12,539.14
4	$1,230.05	-$17,570.37	21	$875.60	-$12,013.45
5	$1,205.70	-$16,855.61	22	$858.26	-$11,489.84
6	$1,181.83	-$16,144.00	23	$841.27	-$10,968.02
7	$1,158.43	-$15,435.13	24	$824.62	-$10,447.70
8	$1,135.50	-$14,728.62	25	$808.30	-$9,928.59
9	$1,113.02	-$14,024.06			
10	-$1,498.97	-$15,988.72			
11	$1,069.39	-$15,366.90			
12	$1,048.22	-$14,748.24			
13	$1,027.47	-$14,132.39			
14	$1,007.14	-$13,519.01			
15	$987.20	-$12,907.77			
16	$967.66	-$12,298.31			

Table 59

Monthly generation of electricity at the third location in the Tippecanoe County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.86	673
2	3.64	762
3	4.48	990
4	5.43	1125
5	5.85	1202
6	6.11	1178
7	5.96	1171
8	5.61	1119
9	5.17	1016
10	4.28	907
11	2.75	582
12	2.43	551
Year	4.55	11277

Table 60

Cash flows and project balances for a standard system at the third location in the Tippecanoe County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	17	$990.73	-$10,558.58
1	$1,364.23	-$19,677.49	18	$971.11	-$9,875.09
2	$1,337.22	-$18,890.48	19	$951.89	-$9,190.89
3	$1,310.75	-$18,107.12	20	-$1,656.91	-$11,173.24
4	$1,284.80	-$17,326.98	21	$914.58	-$10,566.42
5	$1,259.37	-$16,549.64	22	$896.47	-$9,960.05
6	$1,234.44	-$15,774.65	23	$878.73	-$9,353.76
7	$1,210.00	-$15,001.59	24	$861.33	-$8,747.21
8	$1,186.05	-$14,230.00	25	$844.28	-$8,140.01
9	$1,162.57	-$13,459.45			
10	-$1,450.40	-$15,357.15			
11	$1,117.00	-$14,667.35			
12	$1,094.89	-$13,979.63			
13	$1,073.22	-$13,293.61			
14	$1,051.97	-$12,608.89			
15	$1,031.15	-$11,925.08			
16	$1,010.73	-$11,241.77			

Table 61

Monthly generation of electricity at the fourth location in the Tippecanoe County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	3.00	702
2	3.73	774
3	4.63	1016
4	5.56	1144
5	5.96	1217
6	6.20	1191
7	6.03	1182
8	5.71	1135
9	5.31	1042
10	4.48	945
11	2.86	602
12	2.61	590
Year	4.68	11539

Table 62

Cash flows and project balances for a standard system at the fourth location in the Tippecanoe County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	16	$998.63	-$11,538.67
1	$1,347.89	-$19,694.32	17	$978.86	-$10,876.60
2	$1,321.21	-$18,924.31	18	$959.48	-$10,214.63
3	$1,295.05	-$18,158.13	19	$940.49	-$9,552.37
4	$1,269.42	-$17,395.37	20	-$1,668.09	-$11,557.07
5	$1,244.29	-$16,635.62	21	$903.62	-$10,973.05
6	$1,219.66	-$15,878.44	22	$885.74	-$10,389.93
7	$1,195.51	-$15,123.42	23	$868.20	-$9,807.38
8	$1,171.85	-$14,370.12	24	$851.02	-$9,225.06
9	$1,148.65	-$13,618.11	25	$834.17	-$8,642.62
10	-$1,464.05	-$15,534.62			
11	$1,103.62	-$14,863.93			
12	$1,081.78	-$14,195.62			
13	$1,060.36	-$13,529.31			
14	$1,039.37	-$12,864.64			
15	$1,018.80	-$12,201.22			

Table 63

Monthly generation of electricity at the first location in the Marion County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.73	638
2	3.60	748
3	4.48	985
4	5.39	1112
5	5.69	1166
6	6.08	1172
7	6.00	1179
8	5.59	1112
9	5.18	1017
10	4.35	920
11	2.79	588
12	2.47	558
Year	4.53	11194

Table 64

Cash flows and project balances for a standard system at the first location in the Marion County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	17	$890.80	-$13,236.91
1	$1,226.63	-$19,819.22	18	$873.16	-$12,734.65
2	$1,202.34	-$19,175.38	19	$855.88	-$12,235.14
3	$1,178.54	-$18,536.74	20	-$1,751.02	-$14,405.75
4	$1,155.21	-$17,902.98	21	$822.33	-$13,990.92
5	$1,132.35	-$17,273.75	22	$806.05	-$13,580.42
6	$1,109.93	-$16,648.73	23	$790.09	-$13,174.03
7	$1,087.96	-$16,027.60	24	$774.45	-$12,771.57
8	$1,066.42	-$15,410.01	25	$759.12	-$12,372.82
9	$1,045.31	-$14,795.64			
10	-$1,565.34	-$16,851.81			
11	$1,004.34	-$16,322.90			
12	$984.45	-$15,798.60			
13	$964.97	-$15,278.64			
14	$945.86	-$14,762.76			
15	$927.14	-$14,250.69			
16	$908.79	-$13,742.16			

Table 65

Monthly generation of electricity at the second location in the Marion County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.67	626
2	3.50	729
3	4.37	963
4	5.32	1098
5	5.65	1159
6	6.02	1160
7	5.96	1171
8	5.55	1105
9	5.13	1007
10	4.28	906
11	2.72	573
12	2.38	539
Year	4.47	11035

Table 66

Cash flows and project balances for a standard system at the second location in the Marion County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	17	$831.49	-$14,826.41
1	$1,144.96	-$19,903.33	18	$815.03	-$14,431.72
2	$1,122.30	-$19,344.46	19	$798.90	-$14,041.80
3	$1,100.08	-$18,791.71	20	-$1,806.88	-$16,324.14
4	$1,078.31	-$18,244.81	21	$767.58	-$16,023.25
5	$1,056.96	-$17,703.49	22	$752.39	-$15,728.99
6	$1,036.04	-$17,167.47	23	$737.49	-$15,441.24
7	$1,015.53	-$16,636.50	24	$722.89	-$15,159.90
8	$995.42	-$16,110.31	25	$708.58	-$14,884.85
9	$975.72	-$15,588.63			
10	-$1,633.56	-$17,738.85			
11	$937.47	-$17,305.42			
12	$918.91	-$16,878.10			
13	$900.72	-$16,456.70			
14	$882.89	-$16,041.02			
15	$865.42	-$15,630.87			
16	$848.28	-$15,226.06			

Table 67

Monthly generation of electricity at the first location in the Monroe County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.86	653
2	3.75	763
3	4.71	1031
4	5.45	1116
5	5.59	1140
6	6.01	1153
7	5.88	1153
8	5.66	1115
9	5.36	1041
10	4.45	925
11	3.02	624
12	2.69	606
Year	4.62	11319

Table 68

Cash flows and project balances for a standard system at the first location in the Monroe County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	17	$912.88	-$12,645.01
1	$1,257.04	-$19,787.90	18	$894.81	-$12,102.70
2	$1,232.15	-$19,112.42	19	$877.10	-$11,562.38
3	$1,207.76	-$18,441.80	20	-$1,730.23	-$13,691.38
4	$1,183.85	-$17,775.68	21	$842.71	-$13,234.12
5	$1,160.42	-$17,113.72	22	$826.03	-$12,780.33
6	$1,137.45	-$16,455.57	23	$809.68	-$12,329.77
7	$1,114.93	-$15,800.85	24	$793.65	-$11,882.20
8	$1,092.86	-$15,149.23	25	$777.94	-$11,437.39
9	$1,071.23	-$14,500.35			
10	-$1,539.94	-$16,521.50			
11	$1,029.23	-$15,957.03			
12	$1,008.86	-$15,396.62			
13	$988.89	-$14,839.96			
14	$969.31	-$14,286.77			
15	$950.13	-$13,736.74			
16	$931.32	-$13,189.59			

Table 69

Monthly generation of electricity at the second location in the Monroe County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.92	679
2	3.87	800
3	4.70	1029
4	5.49	1128
5	5.81	1189
6	6.18	1191
7	6.12	1200
8	5.84	1161
9	5.44	1067
10	4.55	959
11	3.02	634
12	2.62	588
Year	4.72	11626

Table 70

Cash flows and project balances for a standard system at the second location in the Monroe County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	17	$1,040.63	-$9,221.08
1	$1,432.94	-$19,606.71	18	$1,020.03	-$8,447.08
2	$1,404.58	-$18,748.20	19	$999.84	-$7,670.66
3	$1,376.77	-$17,892.57	20	-$1,609.92	-$9,559.00
4	$1,349.52	-$17,039.34	21	$960.64	-$8,856.31
5	$1,322.80	-$16,188.03	22	$941.63	-$8,152.12
6	$1,296.62	-$15,338.15	23	$922.99	-$7,446.01
7	$1,270.95	-$14,489.22	24	$904.72	-$6,737.53
8	$1,245.79	-$13,640.73	25	$886.81	-$6,026.24
9	$1,221.13	-$12,792.19			
10	-$1,393.00	-$14,610.74			
11	$1,173.26	-$13,840.60			
12	$1,150.04	-$13,071.28			
13	$1,127.27	-$12,302.33			
14	$1,104.96	-$11,533.29			
15	$1,083.08	-$10,763.72			
16	$1,061.64	-$9,993.13			

Table 71

Monthly generation of electricity at the third location in the Monroe County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.87	665
2	3.83	788
3	4.63	1010
4	5.39	1104
5	5.66	1156
6	6.00	1155
7	5.91	1158
8	5.62	1115
9	5.26	1031
10	4.40	926
11	2.95	618
12	2.56	573
Year	4.59	11297

Table 72

Cash flows and project balances for a standard system at the third location in the Monroe County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	17	$958.59	-$11,419.77
1	$1,319.98	-$19,723.06	18	$939.62	-$10,794.55
2	$1,293.85	-$18,982.08	19	$921.02	-$10,169.74
3	$1,268.24	-$18,245.26	20	-$1,687.17	-$12,212.62
4	$1,243.14	-$17,512.19	21	$884.92	-$11,667.54
5	$1,218.53	-$16,782.47	22	$867.40	-$11,124.14
6	$1,194.41	-$16,055.70	23	$850.23	-$10,582.13
7	$1,170.76	-$15,331.49	24	$833.40	-$10,041.20
8	$1,147.59	-$14,609.42	25	$816.90	-$9,501.03
9	$1,124.87	-$13,889.09			
10	-$1,487.36	-$15,837.74			
11	$1,080.77	-$15,199.68			
12	$1,059.38	-$14,564.50			
13	$1,038.41	-$13,931.88			
14	$1,017.85	-$13,301.45			
15	$997.70	-$12,672.85			
16	$977.95	-$12,045.75			

Table 73

Monthly generation of electricity at the first location in the Vanderburgh County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	2.95	676
2	3.69	749
3	4.74	1022
4	5.68	1144
5	5.76	1165
6	5.97	1136
7	6.08	1174
8	5.83	1132
9	5.52	1066
10	4.69	980
11	3.20	671
12	2.80	628
Year	4.75	11543

Table 74

Cash flows and project balances for a standard system at the first location in the Vanderburgh County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	17	$974.72	-$10,987.61
1	$1,342.19	-$19,700.19	18	$955.42	-$10,333.15
2	$1,315.62	-$18,936.11	19	$936.51	-$9,678.54
3	$1,289.57	-$18,175.94	20	-$1,671.99	-$11,691.05
4	$1,264.05	-$17,419.25	21	$899.80	-$11,114.98
5	$1,239.02	-$16,665.63	22	$881.99	-$10,539.99
6	$1,214.50	-$15,914.67	23	$864.53	-$9,965.72
7	$1,190.45	-$15,165.94	24	$847.41	-$9,391.86
8	$1,166.89	-$14,419.02	25	$830.64	-$8,818.05
9	$1,143.79	-$13,673.49			
10	-$1,468.81	-$15,596.57			
11	$1,098.95	-$14,932.55			
12	$1,077.20	-$14,271.01			
13	$1,055.88	-$13,611.59			
14	$1,034.97	-$12,953.91			
15	$1,014.49	-$12,297.61			
16	$994.40	-$11,642.30			

Table 75

Monthly generation of electricity at the second location in the Vanderburgh County, Indiana

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	3.13	717
2	3.85	781
3	4.89	1056
4	5.82	1173
5	5.80	1173
6	6.15	1170
7	6.21	1200
8	6.07	1178
9	5.78	1114
10	4.85	1014
11	3.35	703
12	2.95	662
Year	4.91	11942

Table 76

Cash flows and project balances for a standard system at the second location in the Vanderburgh County, Indiana

Year	Cash flow	Project Balance	Year	Cash flow	Project Balance
0	-$20,468.59	-$20,468.59	17	$931.48	-$12,146.41
1	$1,282.65	-$19,761.51	18	$913.04	-$11,570.37
2	$1,257.26	-$19,059.38	19	$894.97	-$10,995.66
3	$1,232.37	-$18,361.82	20	- $1,712.71	-$13,089.62
4	$1,207.98	-$17,668.46	21	$859.89	-$12,596.62
5	$1,184.06	-$16,978.92	22	$842.87	-$12,106.37
6	$1,160.63	-$16,292.85	23	$826.18	-$11,618.60
7	$1,137.65	-$15,609.85	24	$809.83	-$11,133.03
8	$1,115.13	-$14,929.57	25	$793.79	-$10,649.42
9	$1,093.05	-$14,251.61			
10	-$1,518.54	-$16,243.25			
11	$1,050.21	-$15,648.84			
12	$1,029.42	-$15,058.00			
13	$1,009.04	-$14,470.43			
14	$989.07	-$13,885.80			
15	$969.49	-$13,303.81			
16	$950.30	-$12,724.12			

Table 77

NPV and the IRR for the standard PV system in each location of the selected counties

County	NPV	IRR
Lake County, location 1	$15,869.46	0.491%
Lake County, location 2	$15,816.50	0.460%
Allen County, Location 1	$8,893.37	-4.4270%
Allen County, Location 2	$13,546.39	-0.9440%
Allen County, Location 3	$12,977.71	-1.3190%
Allen County, Location 4	$12,717.64	-1.4940%
Allen County, Location 5	$14,084.69	-0.5980%
Tippecanoe County, Location 1	$15,100.85	0.032%
Tippecanoe County, Location 2	$15,268.58	0.133%
Tippecanoe County, Location 3	$16,097.93	0.625%
Tippecanoe County, Location 4	$15,864.88	0.488%
Marion County, Location 1	$14,135.20	-0.5660%
Marion County, Location 2	$12,970.39	-1.3240%
Monroe County, Location 1	$14,568.96	-0.2950%
Monroe County, Location 2	$17,078.08	1.186%
Monroe County, Location 3	$15,466.84	0.2520%
Vanderburgh County, Location 1	$15,783.53	0.440%
Vanderburgh County, Location 2	$14,934.34	-0.0700%